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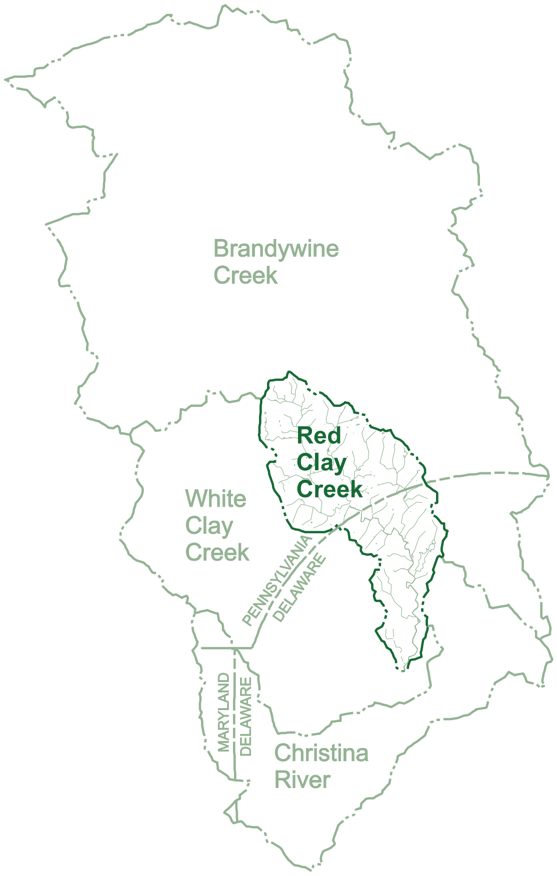
SIMULATION OF STREAMFLOW AND WATER QUALITY IN THE RED CLAY CREEK SUBBASIN OF THE CHRISTINA RIVER BASIN, PENNSYLVANIA AND DELAWARE, 1994-98

Water-Resources Investigations Report 03-4138



In cooperation with the

DELAWARE RIVER BASIN COMMISSION,

DELAWARE DEPARTMENT OF NATURAL RESOURCES AND ENVIRONMENTAL CONTROL, *and the*

PENNSYLVANIA DEPARTMENT OF ENVIRONMENTAL PROTECTION

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by Lisa A. Senior and Edward H. Koerkle

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New Cumberland, Pennsylvania
2003

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CONVERSION FACTORS, DATUMS AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
	Length	
inch (in)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	4,047	square meter
square mile (mi^2)	2.590	square kilometer
	Volume	
million gallons (Mgal)	3,785	cubic meter
cubic foot (ft^3)	0.02832	cubic meter
acre-foot (acre-ft)	1,233	cubic meter
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second
inch per hour (in/hr)	0.0254	meter per hour
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram
pound per hour (lb/h)	0.4536	kilogram per hour
pound per day (lb/day)	0.4536	kilogram per day
ton, short (2,000 lb)	0.9072	megagram
	Hydraulic gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
	Application rate	
pounds per acre (lb/acre)	1.121	kilograms per hectare
tons per acre (ton/acre)	2.242	megagrams per hectare
tons per acre per year [(ton/acre)/yr]	2.242	megagrams per hectare per year
	Temperature	
degree Fahrenheit (°F)	°C=5/9 (°F-32)	degree Celsius

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 1929); horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 1927).

Abbreviated water-quality units used in report:

L, liter
mg/L, milligrams per liter
µg/L, micrograms per liter
mL, milliliter
µS/cm, microsiemens per centimeter at 25 degrees Celsius

SIMULATION OF STREAMFLOW AND WATER QUALITY IN THE RED CLAY CREEK SUBBASIN OF THE CHRISTINA RIVER BASIN, PENNSYLVANIA AND DELAWARE, 1994-98

By Lisa A. Senior and Edward H. Koerkle

ABSTRACT

The Christina River Basin drains 565 square miles (mi^2) in Pennsylvania and Delaware and includes the major subbasins of Red Clay Creek, White Clay Creek, Brandywine Creek, and Christina River. The Red Clay Creek is the smallest of the subbasins and drains an area of 54 mi^2. Streams in the Christina River Basin are used for recreation, drinking-water supply, and to support aquatic life. Water quality in some parts of the Christina River Basin is impaired and does not support designated uses of the stream. A multi-agency, water-quality management strategy included a modeling component to evaluate the effects of point and nonpoint-source contributions of nutrients and suspended sediment on stream water quality. To assist in nonpoint-source evaluation, four independent models, one for each of the four main subbasins of the Christina River Basin, were developed and calibrated using the model code Hydrological Simulation Program–Fortran (HSPF). Water-quality data for model calibration were collected in each of the four main subbasins and in smaller subbasins predominantly covered by one land use following a nonpoint-source monitoring plan. Under this plan, stormflow and base-flow samples were collected during 1998 at 1 site in the Red Clay Creek subbasin and at 10 sites elsewhere in the Christina River Basin.

The HSPF model for the Red Clay Creek subbasin simulates streamflow, suspended sediment, and the nutrients, nitrogen and phosphorus. In addition, the model simulates water temperature, dissolved oxygen, biochemical oxygen demand, and plankton as secondary objectives needed to support the sediment and nutrient simulations. For the model, the basin was subdivided into nine reaches draining areas that ranged from 1.7 to 10 mi^2. One of the reaches contains a regulated reservoir. Ten different pervious land uses and two impervious land uses were selected for simulation. Land-use areas were determined from 1995 land-use data. The predominant land uses in the Red Clay Creek subbasin are agricultural, forested, residential, and urban.

The hydrologic component of the model was run at an hourly time step and calibrated using streamflow data from three U.S. Geological Survey (USGS) streamflow-measurement stations for the period of October 1, 1994, through October 29, 1998. Daily precipitation data from one National Oceanic and Atmospheric Administration (NOAA) gage and hourly data from one NOAA gage were used for model input. The difference between observed and simulated streamflow volume ranged from -0.8 to 2.1 percent for the 4-year period at the three calibration sites. Annual differences between observed and simulated streamflow generally were greater than the overall error for the 4-year period. For example, at a site near Stanton, Del., near the bottom of the basin (drainage area of 50.2 mi^2), annual differences between observed and simulated streamflow ranged from -5.8 to 6.0 percent and the overall error for the 4-year period was -0.8 percent. Calibration errors for 36 storm periods at the three calibration sites for total volume, low-flow-recession rate, 50-percent lowest flows, 10-percent highest flows, and storm peaks were 20 percent or less. Much of the error in simulating storm events on an hourly time step can be attributed to uncertainty in the rainfall data.

The water-quality component of the model was calibrated using nonpoint-source monitoring data collected in 1998 at one USGS streamflow-measurement station and other water-quality monitoring data collected at three USGS streamflow-measurement stations. The period of record for water-quality monitoring was variable at the stations, with an end date of October 1998 but the start date ranging from October 1994 to January 1998. Because of availability, monitoring data for suspended-solids concentrations were used as surrogates for suspended-sediment concentrations, although suspended solids may underestimate suspended sediment and affect apparent accuracy of the suspended-sediment simulation. Comparison of observed to simulated loads for five storms in 1998 at the one nonpoint-source monitoring site at Wooddale, Del., indicates that simulation error commonly is as large as an order of magnitude for suspended sediment and nutrients. The simulation error tends to be smaller for dissolved *nutrients than particulate nutrients. Errors of 40 percent or less for monthly or annual values indicate a fair to good water-quality calibration according to recommended criteria, with much larger errors possible for individual storm events. Assessment of the accuracy of the water-quality calibration under stormflow conditions is limited by the sparsity of available water-quality data in the basin.*

Users of the Red Clay Creek HSPF model should be aware of model limitations and consider the following when predictive scenarios are desired: streamflow-duration curves indicate the model simulates streamflow reasonably well when evaluated over a broad range of conditions and time, although streamflow and the corresponding water quality for individual storm events may not be well simulated; streamflow-duration curves for the simulation period compare well with duration curves for the 57.5-year period ending in 2001 at Wooddale, Del., and include all but the extreme high-flow and low-flow events; calibration for water quality was based on sparse data, with the result of increasing uncertainty in the water-quality simulation.

INTRODUCTION

The Christina River Basin (fig. 1), which includes Red Clay Creek (54 mi^2), White Clay Creek (drainage area of 108 mi^2), Brandywine Creek (327 mi^2), and the Christina River itself (76 mi^2), drains approximately 565 mi^2 in southeastern Pennsylvania, northern Delaware, and a small part of northeastern Maryland. The Christina River and its tributaries provide drinking water for more than 40 percent of the residents of Chester County, Pa., and more than 50 percent of the residents of New Castle County, Del.

Stream waters of the Christina River Basin are used for public water supply and recreation and to support aquatic life. Some of these uses are threatened because water quality has been impaired by point and nonpoint sources of contamination. Causes of impairment have been identified as sediment, nutrients, and bacteria (Greig and others, 1998). In addition, some agricultural areas of the basin are undergoing urbanization, and the effects of land-use changes on water quality and quantity are unknown. The States of Delaware and Pennsylvania need tools to evaluate alternative approaches for correcting present water-quantity and water-quality problems and for forecasting future conditions.

A 5-year water-quality management strategy for the Christina River Basin, starting in 1995, was conceived and directed by the Delaware Department of Natural Resources and Environmental Control (DNREC), Pennsylvania Department of Environmental Protection (PADEP), Chester County Conservation District (CCCD), Water Resources Agency (WRA) of New Castle County, Chester County Water Resources Authority (CCWRA), New Castle County Conservation District, Delaware River Basin Commission (DRBC), U.S. Environmental Protection Agency (USEPA), watershed groups and other concerned organizations, groups, and individuals. To assist with the water-quality management process, the U.S. Geological Survey (USGS) developed a nonpoint-source monitoring plan and constructed a hydrologic and water-quality model of the basin to estimate sediment and nutrient contributions from nonpoint sources. USGS conducted the Christina River Basin nonpoint-source monitoring and modeling in cooperation with DRBC, DNREC, and PADEP.

A widely used model, Hydrological Simulation Program—Fortran (HSPF) (Bicknell and others, 1997), was selected as a tool for the water-resources planning and management needs for the Christina River Basin. Each of the four major subbasins in the Christina River Basin was modeled separately because HSPF can be applied only to free-flowing, non-tidal streams, and the lower reaches of the Christina River and its tributaries, Brandywine Creek, White Clay Creek and Red Clay Creek are tide-affected. The watershed model, HSPF, can be used to simulate the delivery of nonpoint-source contaminants to main-stem streams. The model can simulate hydrologic processes, physical transport of nonpoint-source contaminants, and instream chemical reactions. Data required for this watershed model include concentrations of contaminants of interest over a range of hydrologic conditions from various land-use areas that are expected to differ in contribution of nonpoint-source contaminants and hydrologic response.

The nonpoint-source water-quality sampling plan, executed in 1997-98, provided streamflow, nutrient, and suspended solids data that were used to (1) estimate concentrations and loads of the selected constituents from various land uses in the Christina River Basin; and (2) calibrate an HSPF model of each major subbasin for these selected constituents. Nonpoint-source water-quality and

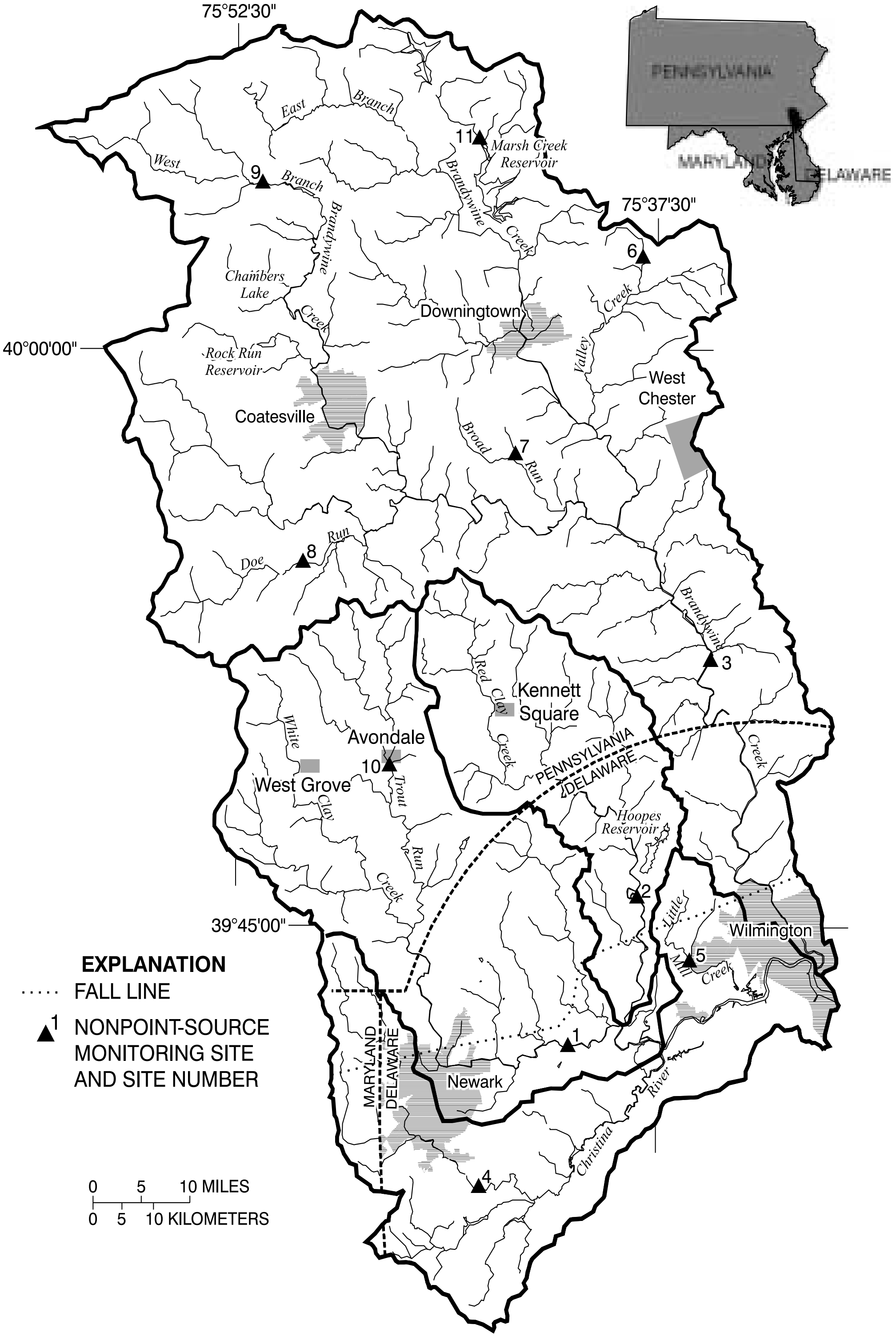

Figure 1. Location of the Christina River Basin and its four major subbasins and water-quality monitoring sites, Pennsylvania, Delaware, and Maryland.

streamflow data were collected at four main-stem sites on the lower free-flowing reaches of the Christina River and Brandywine, White Clay, and Red Clay Creeks, and at seven subbasin sites throughout the Christina River Basin selected principally for land-use characterization (fig. 1; table 1). All sites were equipped for continuous streamflow recording and automated water-quality sampling. Six sites were at existing USGS streamflow-measurement stations (gages), one site (01480095) was at a discontinued streamflow-measurement station recommissioned for the study, and four new streamflow / water-quality sites (01480878, 01480637, 014806318, 01478137) were constructed for the study (table 1).

The HSPF model for the largest of the subbasins, the Brandywine Creek Basin, was developed first (Senior and Koerkle, 2003a) and is the basis for models in the other subbasins, including the Red Clay Creek Basin. The hydrologic and water-quality characteristics for a specific type of agriculture, mushroom farming, that is present in the Red Clay Creek Basin was calibrated during the development of the HSPF model for the White Clay Creek Basin (Senior and Koerkle, 2003b). Model-input parameters affecting suspended-sediment and nutrient contributions from other selected land uses were calibrated for the Brandywine Creek model and transferred to the White Clay Creek model, where applicable. An overview of the entire monitoring and modeling effort by USGS is presented in the last of the model reports for the Christina River Basin (Senior and Koerkle, 2003c). The HSPF model may be used to evaluate options for managing contaminants from nonpoint and point sources and can provide a comprehensive method of calculating nonpoint-source loads to meet total maximum daily load (TMDL) requirements. Currently (2003), TMDL assessments are ongoing in the Christina River Basin.

Purpose and Scope

This report describes the development of an HSPF model constructed for the Red Clay Creek subbasin of the Christina River Basin and subsequent hydrologic and water-quality simulations. The main objective of modeling was to create a tool to estimate nonpoint-source loads of selected constituents over a range of hydrologic conditions. The model description includes explanation of the general aspects, model structure, spatial segmentation, parameterization, and limitations. In addition, data used for model-input and calibration are

Table 1. *Nonpoint-source water-quality monitoring sites, Christina River Basin, Pennsylvania and Delaware (see figure 1 for location of sites)*

Type of nonpoint-source water-quality sampling site	Site number on map	Location	U.S. Geological Survey streamflow-measurement station number	Drainage area (square miles)
		Overall Basin Main-Stem Site		
Main stem (White Clay Creek)	1	White Clay Creek near Newark, Del.	01479000	89.1
Main stem (Red Clay Creek)	2	Red Clay Creek near Wooddale, Del.	01480000	47.0
Main stem (Brandywine Creek)	3	Brandywine Creek at Chadds Ford, Pa.	01481000	287
Main stem (Christina River)	4	Christina River at Cooch's Bridge, Del.	01478000	20.5
		Single Land-Use Basins		
Urban	5	Little Mill Creek near Newport, Del.	[1]01480095	5.24
Residential - sewered	6	Unnamed tributary to Valley Creek at Highway 30 at Exton, Pa.	[2]01480878	1.47
Residential - unsewered (on septic systems)	7	Little Broad Run near Marshallton, Pa.	[2]01480637	.6
Agricultural - row crop	8	Doe Run above tributary at Springdell, Pa.	[2]014806318	11.7
Agricultural - livestock	9	West Branch Brandywine Creek near Honey Brook, Pa.	01480300	18.7
Agricultural - mushroom	10	Trout Run at Avondale, Pa.	[2]01478137	1.31
Forested	11	Marsh Creek near Glenmoore, Pa.	01480675	8.57

[1] Streamflow-measurement station restarted for study.

[2] New streamflow-measurement station constructed for this study.

described. The HSPF model for the Red Clay Creek subbasin was used to simulate streamflow, water temperature, suspended sediment, and the nutrients, nitrate, ammonia, and orthophosphate, on an hourly basis. Additionally, the model was used to simulate water temperature, dissolved oxygen, biochemical oxygen demand, and plankton as secondary objectives needed to support the sediment and nutrient simulations on an hourly basis for the calibration period October 1, 1994, through October 29, 1998. Calibration results, analysis of model sensitivity to parameter variation, and model limitations are presented and discussed for simulations of streamflow and water-quality constituents. Examples of model applications are given, including quantification of nonpoint-source loads from selected areas of the Red Clay Creek Basin.

Previous Studies

Data on water quality and stream invertebrates collected at two sites in the Red Clay Creek Basin as part of a long-term monitoring effort in Chester County, Pa., were evaluated for the period 1969-80 by Moore (1987) and published for the period of 1981-94 by Reif (1999). Concern about the presence of contaminants in sediments in the Red Clay Creek Basin led to a study of metals and anthropogenic organic compounds in soils and sediments in the basin (Rice, 1993). Surface-water quality was related to ground-water quality and land use in a study of ground-water quality in the Red Clay Creek Basin using data collected in 1993-94 (Senior, 1996).

Acknowledgments

Water-use data were obtained with the assistance of Gerald Kauffman of the WRA at the University of Delaware, Robert Struble of the Brandywine Valley Association, and Craig Thomas of CCWRA. Water-quality data for PADEP monitoring sites in Pennsylvania was provided by William Goman of PADEP. Information about agricultural uses was obtained from Daniel Greig and others at CCCD and the New Castle County Conservation District. Overall guidance for the project was provided by the modeling technical committee of the Christina River Basin Water-Quality Management group, including David Pollison of DRBC, Richard Greene and Hassan Mirsajadi of DNREC, William Goman of PADEP, Jan Bowers of CCWRA, Gerald Kauffman of WRA, and Larry Merrill of USEPA. In addition to those mentioned here, those who helped identify the need for the project include Nancy Goggin and Jenny McDermott of DNREC and Niki Kasi and Russell Wagner of PADEP.

DESCRIPTION OF STUDY AREA

The Red Clay Creek drains 54 mi^2 in southeastern Pennsylvania and northern Delaware. The headwaters of Red Clay Creek are in Chester County, Pa., and the stream flows south into New Castle County, Del., where it is tributary to the White Clay Creek, which itself is tributary to the Christina River (fig. 1). The largest population center in the basin is the borough of Kennett Square, Pa. The confluence of the East and West Branches of Red Clay Creek is near the State line between Pennsylvania and Delaware. Burroughs Run is the largest named tributary in the Red Clay Creek Basin.

Physical Setting

The Red Clay Creek Basin encompasses areas in the Piedmont Physiographic Province in southeastern Pennsylvania (Berg and others, 1989) and the Piedmont and Coastal Plain Physiographic Provinces in northern Delaware. The topography of the Piedmont Physiographic Province is characterized by gently rolling uplands dissected by narrow valleys, whereas the topography of the Coastal Plain Physiographic Province is characterized by nearly flat terrain. Elevation of the land surface in the Red Clay Creek Basin ranges from near sea level to about 560 ft above sea level. Most of the basin is in the Piedmont Physiographic Province, which is underlain predominantly by metamorphic rocks of igneous and sedimentary origin. A small part in the southern tip of the basin, below the Fall Line (fig. 1), is in the Coastal Plain Physiographic Province, which is underlain by unconsolidated sediments. The Fall Line forms the boundary between uplands of the Piedmont and nearly flat terrain of the Coastal Plain.

Climate

The Red Clay Creek Basin has a modified humid continental climate. Winters are mild to moderately cold and summers are warm and humid. Normal mean annual air temperatures at National Oceanic and Atmospheric Administration (NOAA) weather station southwest of the basin at Newark (fig. 1), for 1971-2000 is 54.8°F (12.7°C) (National Oceanic and Atmospheric Administration, 2000a). Normal mean annual air temperatures (1971-2000) are cooler north of the basin (51.5°F at Coatesville, Pa.) than south of the basin (54.4°F at Wilmington, Del.) (National Oceanic and Atmospheric Administration, 2000a, 2000b). At Newark, the normal mean temperature (1971-2000) for January, the coldest month, is 32.5°F (0.3°C), and normal mean temperature (1971-2000) for July, the warmest month, is 76.4°F (24.7°C). Normal mean annual precipitation (1971-2000) at Newark is 45.35 in. Precipitation is distributed fairly evenly throughout the year. In southeastern Pennsylvania and northern Delaware, snowfall is mainly in the months of December, January, February, and March.

Geology

The Red Clay Creek Basin is underlain by Paleozoic-age and older metamorphosed sedimentary and igneous rocks. The metasediments include schist, quartzite, and carbonate rocks. The Paleozoic-age and older rocks have been folded, faulted, and metamorphosed various times during their history, resulting in a structurally complex assemblage. The primary structural trends are east-northeast. In the southernmost part of the basin, below the Fall Line (fig. 1), these rocks are overlain by Cretaceous-age and quaternary-age sands and gravels of the Coastal Plain. These Coastal Plain sediments were deposited on the older bedrock, forming beds that thicken to the southeast.

Soils

Five soil associations and 15 soil series are found in the Red Clay Creek Basin (fig. 2) (Kunkle, 1963; Matthews and Lavoie, 1970). In general, the soils have developed in place and are derived from the underlying bedrock. Most of the soils are developed on schist, gneiss, and quartzite, with the exception of the Hagerstown-Conestoga-Guthrie association, which is developed on carbonate rocks, and soils south of the Fall Line, which are developed on unconsolidated Coastal Plain sediments.

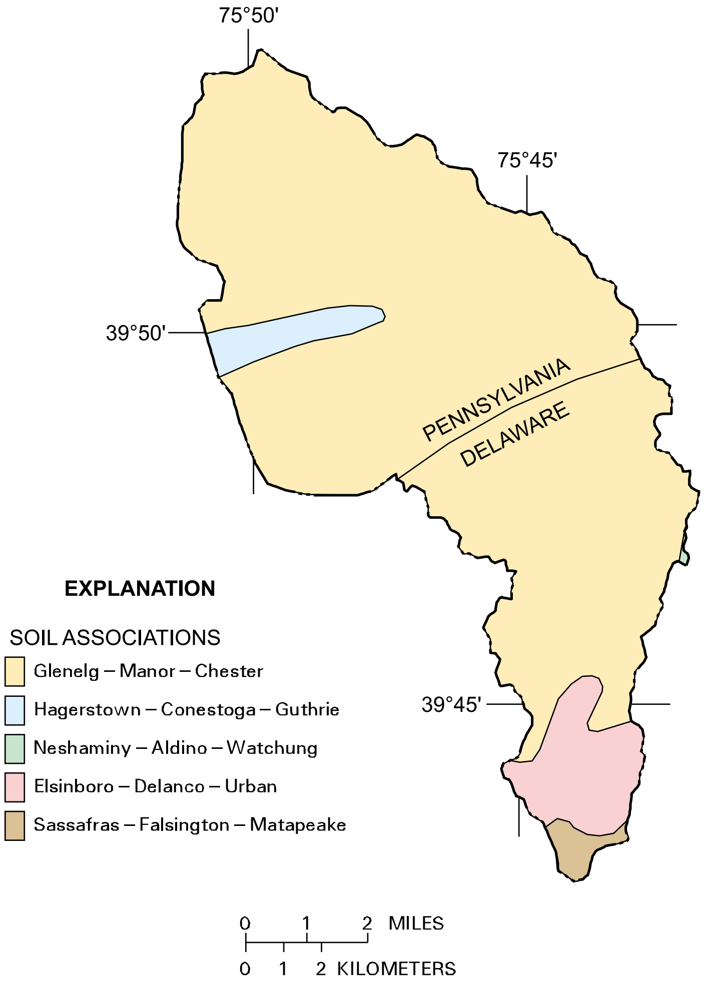

Figure 2. Mapped soil associations in the Red Clay Creek Basin, Pennsylvania and Delaware.

The principal soil association is Glenelg-Manor-Chester, which overlies almost 90 percent of the Red Clay Creek Basin. Soils in this association generally are gently to moderately sloping and well drained. Surface permeabilities of individual soil series range from 0.6 to 2.0 in / hr except for the Aldino, Hagerstown, Manor, and Neshaminy series that are limited in extent. Permeabilities in these four series range from 2.0 to 6.3 in / hr.

Hydrology

The metamorphosed sedimentary and igneous rocks that underlie most of the Red Clay Creek Basin form fractured-rock aquifers. The competent bedrock is overlain by weathered rock, saprolite, and soil. The bedrock and overlying materials are recharged by precipitation. Ground water flows through the secondary openings (fractures) in fractured-rock aquifers and discharges locally to streams and springs. The sands and gravels of the Coastal Plain in the southern tip of the Red Clay Creek Basin also are recharged by precipitation. Recharge to these sedimentary beds may discharge locally to streams and also may recharge the individual beds that dip to the southeast. Ground water in the Coastal Plain sands and gravels flows through primary openings (pore spaces).

Approximately 40 percent of the annual input of precipitation to the Red Clay Creek Basin is discharged as streamflow (Vogel and Reif, 1993). The remaining precipitation is lost to evapotranspiration. Streamflow is composed of, on average, 65-percent base flow (ground-water discharge) and 35-percent surface runoff (Vogel and Reif, 1993) with between year variations of 10 percent not uncommon. Streams in the Red Clay Creek Basin mostly are low to moderate gradient. Channel bottoms in higher gradient reaches and forested areas primarily are exposed bedrock, sand, and gravel. In low-gradient reaches and pools, channel bottoms are covered in places with finer-grained sediment.

A number of hydraulic structures are located throughout the Red Clay Creek Basin. The primary purposes of these structures are impoundment. In the lower Red Clay Creek Basin, Hoopes Reservoir, on a tributary to the Red Clay Creek, impounds 6,300 acre-feet. Hoopes Reservoir is regulated actively to store water pumped from the Brandywine Creek for use as drinking-water supply to the city of Wilmington, Del. Little water is released from Hoopes Reservoir to Red Clay Creek, although, occasionally, water is released to augment flows. The remaining structures consist of historic low-head dams situated on the mainstem Red Clay Creek.

Land Use

Land use in the Red Clay Creek Basin in 1993-95 as determined from aerial photographs was predominantly agricultural, forested, and residential, with lesser amounts of open and urban land, including industrial and commercial uses (Greig and others, 1998). From data compiled for the 1993-95 period, estimated land use in the basin is about 37 percent agricultural, 28 percent residential, 24 percent forested, 5 percent open, 3 percent urban, and 2 percent other.

Water Use

Water use in the Red Clay Creek Basin consists of withdrawals and discharges of surface water and ground water for residential, commercial, and industrial consumptive and non-consumptive uses. Commonly, water from a surface-water intake or ground-water well is withdrawn, used as needed, and returned to the source as waste flow minus consumptive losses. Waste flows return to surface waters through wastewater-treatment facilities and industrial discharges. In the less urbanized parts of the basin, ground water is the primary water supply through wells on individual properties. Wastewater in these non-sewered areas typically is discharged and infiltrates to ground water mainly through septic systems on individual properties. In and near population centers, public water suppliers use surface water as the main water source but may augment with ground water. A few public water systems rely on ground water for supply. Wastewater in urban areas generally is carried by sewers to treatment facilities that typically discharge to streams although alternative methods have been recently used in the area. Two municipal systems for disposal of treated waste water through land treatment (spray irrigation) have been constructed in the Red Clay Creek Basin since 1995.

Some of the larger public water systems maintain complex withdrawal, distribution, and discharge facilities that allow water redistribution within or between basins. Although no water is directly withdrawn from Red Clay Creek for drinking-water supply, water is withdrawn for this purpose from White Clay Creek just below the confluence of Red Clay Creek, treated, and put in a distribution system that supplies users in Red Clay, White Clay, and Brandywine Creek Basins. In addition, the City of Wilmington withdraws from the Brandywine Creek Basin but commonly stores some of this water in the Hoopes Reservoir in the Red Clay Creek Basin. Occasionally, water is released from Hoopes Reservoir to augment low flows in the Red Clay Creek. Some of the water purveyors that supply drinking water in the Red Clay Creek Basin also have the option to import water from the West Branch Octoraro Creek in the Susquehanna River Basin, which borders the northwestern edge of the Christina River Basin.

In the Christina River Basin, impaired water quality has been linked to water-use processes such as wastewater treatment, industrial discharges, and septic systems (Greig and others, 1998). The effects of these processes on streamflow and water quality in the Red Clay Creek can vary depending on their location and volumes.

DESCRIPTION OF MODEL

The numerical model HSPF includes a set of computer codes for algorithms used to simulate the hydrologic response of land areas to precipitation and flow through stream channels in a basin. The algorithms used to simulate these processes are described in detail by Bicknell and others (1997). The precipitation-driven simulation of streamflow includes response from pervious and impervious land areas and routing of water in the stream channel. Pervious and impervious land areas are assigned hydrologic-response parameters on the basis of land use and other characteristics such as slope. Streamflow routing is controlled by channel characteristics of model reaches. The HSPF model can be used to simulate free-flowing streams and well-mixed reservoirs but cannot be used to simulate tidal streams.

The HSPF model structure requires dividing the basin into multiple elements whose number and size reflect the range of selected hydrologic characteristics and the scope of available input data. A first step in structuring the model is segmenting the basin. Segmentation commonly is delimited by climatological or physical characteristics that would determine specific hydrologic response to precipitation. When little differences are apparent in physical characteristics, segmentation may be determined by the number and location of precipitation stations available for input. The basin also is subdivided into pervious (PERLND) and impervious (IMPLND) land-use types. Within each model segment, each PERLND and IMPLND is assigned hydrologic-response parameters. These parameters control the partitioning and magnitude of hydrologic outputs in response to input precipitation. The stream channel is then partitioned into reaches (RCHRES). A RCHRES generally is delimited by major flow inputs (tributaries, etc.), calibration locations (streamflow gages, water-quality sites), and time-of-travel considerations. Each RCHRES receives flow from land area draining to that reach and from upstream RCHRES. Runoff, interflow, and ground water from each PERLND and IMPLND is directed to a RCHRES. Point-source withdrawals and discharges can be specified for the RCHRES where they are located. The overall model structure including assignment of time-series data (meteorological, streamflow, point-source withdrawals, and discharges), reach connections, land-area to reach relations, channel characteristics, and land-use category response parameters are described in the user control input (UCI) file.

The hydrologic response of PERLNDs and IMPLNDs is handled by their respective modules. The water budget, or predicted total runoff, for pervious land is simulated using the section PWATER of the PERLND module. Total runoff is the sum of base flow (ground-water discharge to streams), interflow, and surface runoff. The hydrologic processes modeled by PWATER include infiltration of precipitation, interception by plant materials, evapotranspiration, surface runoff, interflow, and ground-water flow. Precipitation may be evaporated from, move through, and(or) remain in storage in surface interception, surface detention, interflow, upper soil zone, lower soil zone, and active ground water. Predicted total runoff for impervious land is simulated using the section IWATER of the IMPLND module. The hydrologic processes simulated by IWATER include retention, routing, and evaporation of water from impervious areas.

Runoff derived from snowfall, snow accumulation, and snow melt is simulated using the module SNOW. Meteorological data are used to determine when precipitation is rain or snow, calculate an energy balance for the snow pack, and determine the effect of heat fluxes on the snow pack. The amount of precipitation that occurs as snow in the Red Clay Creek Basin is highly variable. Some years have no snow; others may have snow and snow cover for most of the winter months. The assumption was made that simulating snow would result in a more accurate streamflow simulation. However, periods cold enough to have substantial snowfall also may have poor observed streamflow record because of channel ice at streamflow-measurement locations and consequent poor-quality calibration data.

The routing of water in the stream channel is simulated by the section HYDR of the module RCHRES. Routing is based on kinematic-wave or storage-routing methods, where flow is assumed to be unidirectional. HYDR calculates rates of outflow and change in storage for a free-flowing reach or completely mixed reservoir. RCHRES inflows include runoff from PERLND and IMPLND land areas draining to that reach, water from upstream RCHRES, precipitation falling directly on the RCHRES surface area, and other discharges to the reach. RCHRES outflows include flow to the downstream reach, withdrawals from the reach, and evaporation. A series of reaches are used to represent the actual network of stream channels.

For each RCHRES, a relation between depth, surface area, volume, and outflow (discharge) is assigned and specified in an F-TABLE. When available, data for the F-TABLEs were derived from stage-discharge ratings for streamflow-measurement stations at RCHRES endpoints. For reaches that do not end at a streamflow-measurement station, data for the F-TABLE were generated using the computer program XSECT. XSECT calculates depth-discharge relations for a hypothetical stream channel, assuming a trapezoidal shape and using specified stream length, stream slope, channel width, channel depth, floodplain slope, Manning’s n for the stream channel, and Manning’s n for the floodplain.

The water-quality component of HSPF simulates contributions from pervious and impervious land areas and accounts for selected chemical reactions in the stream reaches. The model includes algorithms to describe the transport of constituents from the land to the stream reach, chemical reactions affecting selected constituents in the reach, sediment exchange between channel bed and water column, and the temperature of runoff and water in a reach. Contributions of constituents from land areas may vary by land-use category in the model. Water-quality simulation requires a calibrated hydrodynamic model.

Water temperature, dissolved oxygen, and carbon dioxide in surface runoff, interflow, and ground-water outflows from pervious land areas are simulated in the PWTGAS section of the PERLND module and from impervious lands in the IWTGAS section of the IMPLND module. Water temperature in each reach is simulated by the HTRCH section of the module RCHRES and includes heat transported by PERLND and IMPLND outflows and point-source discharges. The main heat-transfer processes considered are transfer by advection, where water temperature is treated as a thermal concentration, and transfer across the air-water interface. Heat gain and loss by radiation also is simulated. Meteorological data, such as air temperature and wind speed, are used in the simulation of stream temperature. In-stream dissolved oxygen concentrations are simulated by the OXRX section of the RCHRES module that includes the processes of advections, aeration, and consumption of oxygen by biological oxygen demand.

The simulation of sediment includes transport of sediment from land areas and transport within the stream channel. Sediment release from pervious areas is simulated in the SEDMNT module. Sediment available for transport is generated by detachment associated with rainfall. Detached sediment is transported to the stream as washoff. Scour also may be simulated for pervious areas. Sediment release for impervious areas is simulated in the SOLIDS module. Buildup of solids on impervious areas is transported to the stream in surface runoff. Sediment transport in the stream channel is simulated in the SEDTRN module. The channel simulation includes scour and deposition of bed material but not bank material.

The transport of nutrients from the land to the stream is simulated in the PQUAL module for pervious areas and IQUAL module for impervious areas. For pervious areas, nutrients associated with soil are transported with sediment in surface runoff. Nutrients also enter the stream in interflow and ground-water discharge. For impervious areas, nutrients accumulate on the surface and are washed into the stream during storm events. Once in the stream, the transport and chemical interactions of nutrients are simulated by the modules NUTRX and PLANK. The NUTRX and PLANK modules require an active OXRX module for instream simulation of dissolved oxygen and biological oxygen demand. The NUTRX module includes physical transport and inorganic chemical reactions affecting nutrients. The PLANK module simulates the effect of phytoplankton and periphyton in the stream and includes uptake and release of nutrients.

DATA FOR MODEL INPUT AND CALIBRATION

HSPF requires a large amount of data to characterize effectively the hydrologic and water-quality response of the watershed to precipitation and other inputs (Donigian and others, 1984). Data used in creating and defining the model structure and parameters were derived principally from spatial analysis of basin characteristics and previously published information. Spatial data analyzed for model construction includes land use, land-surface slope, and soil associations. Time-series input for streamflow and water-quality simulation include meteorologic, precipitation quality, water-use, and discharge quantity and quality data. Calibration data consisted of observed streamflow for the hydrodynamic simulation and observed water temperatures and laboratory analyses of grab and composite stream samples for the water-quality simulation.

Time-series data for model input and model output were processed and stored in the binary format Watershed Data Management (WDM) database. The WDM format is the standard format for input to and output from HSPF. The computer programs ANNIE (Flynn and others, 1995), IOWDM (Lumb and others, 1990), METCMP (Alan Lumb, U.S. Geological Survey, and John Kittle, Aqua Terra Consultants, written commun., 1995), WDMUtil (U.S. Environmental Protection Agency, 1999), and GenScn (Kittle and others, 1998) were used in the processing of WDM time-series data. Parameter and model-structure data were processed independently of the time-series data and are defined in the UCI, an ascii text file.

Model-Input Data

The types, resolution, and quantity of the data needed for input are determined by (1) the hydrologic and water-quality processes to be included in the model; (2) the time step selected for simulation; (3) the length of the simulation period; and (4) the spatial scale of interest. For example, simulation of streamflow requires time-series inputs of precipitation, potential evaporation, withdrawals from streams, and discharges to streams. Simulation of stream water quality requires, in addition to parametric estimates of chemical inputs from pervious and impervious land areas, time-series inputs of water-temperature data and constituent loads in point-source discharges. Because only a limited amount of recorded water-temperature data were available for the Red Clay Creek Basin that could be used as model input, water temperature was simulated. The simulation of water temperature requires input of additional meteorological data.

The Red Clay Creek model was run on a 1-hour time step. Time-series data available only at time intervals greater than hourly required disaggregation. For the simulation period of October 1, 1994, through October 1998, more than 4 years of reported or estimated hourly values were needed for the time-series input data sets.

Meteorologic Data

Simulation of mean hourly streamflow in HSPF required inputs of hourly precipitation and potential evapotranspiration. Daily precipitation data used for model input were selected from local NOAA meteorologic stations based on Thiessen polygon delineations and analysis of the precipitation records. In addition, hourly precipitation data for the Red Clay Creek Basin were collected at one of nine raingages installed in the Christina River Basin specifically for this modeling effort. However, these data were not used because of their short period of record (December 1997 to October 1998), which only covered about a quarter of the model-simulation period, their limitations to any future extension of the simulation period, and overall poor quality (related to raingage malfunctions). Daily precipitation data were disaggregated using METCMP into hourly data based on hourly precipitation recorded at the NOAA station at the Wilmington, Del., Airport. Daily potential evapotranspiration data were disaggregated at the time of simulation.

Thiessen polygons created for all local NOAA meteorologic stations overlaid the Red Clay Creek Basin in four areas (fig. 3). The Porter Reservoir station polygon covered about 60 percent of the central basin; Coatesville 2 W station polygon covered about 20 percent of the northwest basin; Newark University Farm station polygon covered about 10 percent of the northwest basin; and Wilmington Airport station polygon covered about 10 percent of the southern basin. Precipitation for these meteorologic stations is listed in table 2.

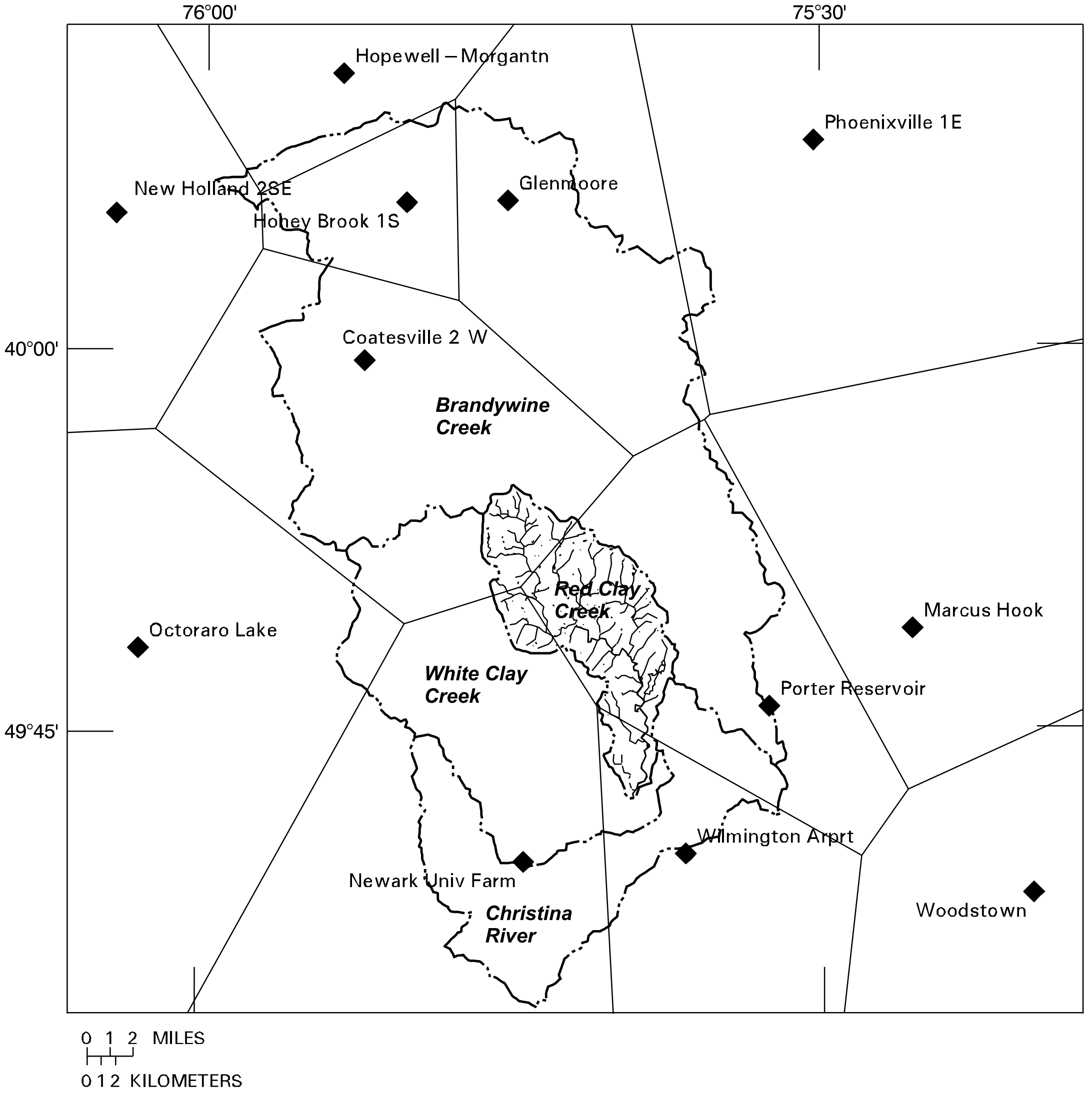

Figure 3. Location of National Oceanic and Atmospheric Administration meteorologic stations and calculated Thiessen polygons in the vicinity of the Red Clay Creek Basin, Pennsylvania and Delaware.

The 1994-98 period of simulation spanned relatively normal, dry, and wet years of precipitation. For example, the long-term (1971-2000) “normal” annual precipitation as calculated from monthly precipitation at Wilmington Porter Reservoir is 49.4 in. (Delaware State Climatologist, 2001). In comparison to the “normal” annual precipitation at Porter Reservoir, the years 1994 and 1995 and the 10-month period of 1998 were within 15 percent of normal (table 2). The greatest departures were in 1996 when annual precipitation was 39 percent above normal and in 1997 when annual precipitation was 21 percent below normal.

Table 2. *Annual and total precipitation at meteorologic stations near the Red Clay Creek Basin, Pennsylvania and Delaware, 1994-98*

Raingage (fig. 3)	Precipitation, in inches					
	1994	1995	1996	1997	[1]1998	Total
Coatesville 2 W	50.2	47.2	75.1	39.3	39.0	250.8
Porter Reservoir	57.4	45.1	68.9	38.9	37.0	247.3
Newark University Farm	43.9	40.6	60.5	36.9	32.2	214.1
Wilmington Airport	45.4	40.1	52.4	28.0	34.2	200.1

[1] Precipitation for January 1 through October 29.

Comparison of the period-of-simulation precipitation totals shows substantial differences (table 2) between meteorologic stations. For the 4-year 10-month period, Porter Reservoir reported 23 percent more precipitation than Wilmington Airport, which is about 10 mi to the south. The monthly distribution of precipitation (fig. 4) indicates that differences of 30 percent or more between the Porter Reservoir and Wilmington Airport stations were common. This difference shows up as a consistent recording bias over the period of simulation (fig. 4). Comparison of precipitation data at Porter Reservoir to precipitation data at other NOAA meteorologic stations near the Red Clay Creek Basin shows precipitation totals for the period to be less at Newark University Farm southwest of the basin (-13 percent) and greater at Coatesville 2 W to the north of the basin (3 percent) (table 2). Some of the differences between gages may be due to spatial variability. The precipitation record indicates that annual totals decrease from northeast to southwest across the basin. Although some discrepancies in total precipitation can be expected across the basin, a review of numerous raingage-network studies in the eastern United States showed that annual differences at adjacent gages averaged 5 percent or less (Winter, 1981) and that those differences tend to decrease over longer periods of record and increase for shorter periods.

Because the Porter Reservoir Thiessen polygon covers 60 percent of the basin, Porter Reservoir data were selected as the sole precipitation input to Red Clay Creek Basin model. However, adjustment factors were applied to the Porter Reservoir precipitation record to account for the northeast to southwest decrease in observed precipitation, to complete a satisfactory water balance for the simulation period (Donigian and others, 1984), and because of the unusually large differences in total rainfall between meteorologic stations proximate to Red Clay Creek Basin. The final factors applied to adjust the precipitation at Porter Reservoir to input in the Red Clay Creek Basin were from north to south, 0.9, 0.87, and 0.85 for the three segment areas of the Red Clay Creek model.

Precipitation data may contain a number of errors. Measurement errors, whereas known in general, are not specifically known for the gages used in the Red Clay Creek model. These errors may include malfunctioning equipment, incorrect calibration, and environmental effects (Winter, 1981). Precipitation data from NOAA meteorologic stations adjacent to the station selected for the model show departures as great as 15 percent over the simulation period, whereas individual storm events have departures as much as 300 percent. Thus, storms with substantial precipitation in one

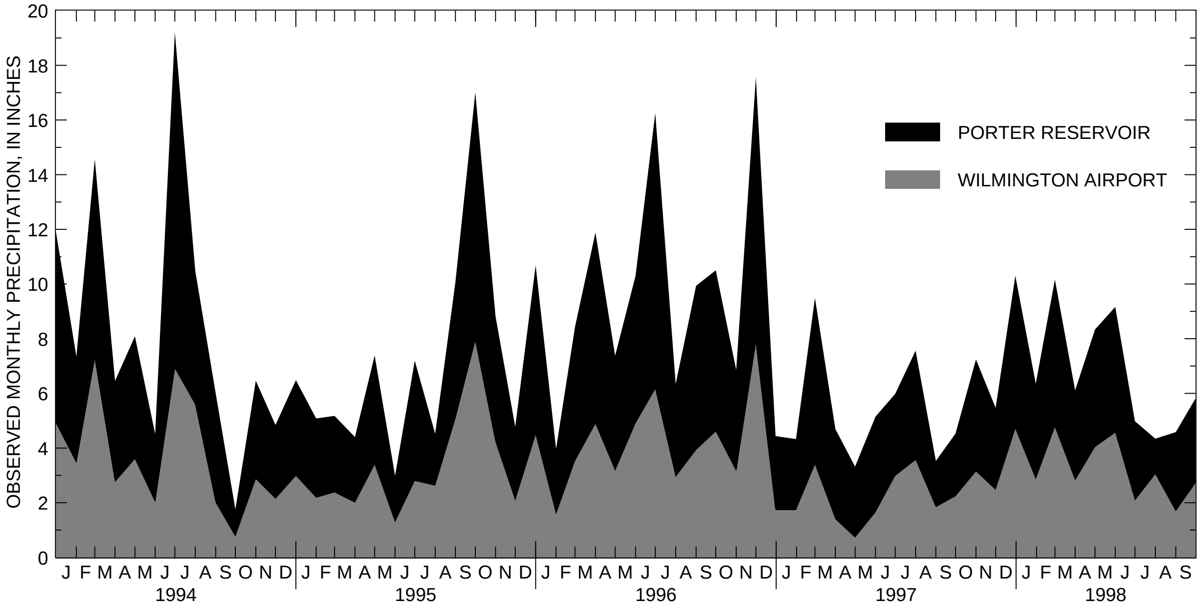

Figure 4. Monthly precipitation measured at the Wilmington Airport National Oceanic and Atmospheric Administration and Porter Reservoir meteorologic stations near the Red Clay Creek Basin, Pennsylvania and Delaware, 1994-98.

part of the basin may appear to result in little or no streamflow response. Disaggregation of daily precipitation values to hourly values by applying the hourly distribution of precipitation at the Wilmington, Del., Airport excludes the spatial and temporal variations in rainfall distribution across the Red Clay Creek Basin. Disaggregation errors can appear as timing shifts in storm hydrographs.

Potential evapotranspiration at the Wilmington, Del., Airport meteorologic station was used for model input. The daily estimates of potential evapotranspiration for Wilmington were calculated by the Northeast Regional Climate Center using a method described by DeGaetano and others (1994). Monthly totals of potential evapotranspiration are shown in figure 5. Disaggregation of daily potential evapotranspiration was done automatically by HSPF. Daily potential evapotranspiration totals were divided into 24 equal hourly values during an HSPF run.

Snow simulation requires precipitation, air temperature, solar radiation, dewpoint, and wind-speed data. Hourly air temperature, solar radiation, dewpoint, and wind speed from Wilmington, Del., Airport were compiled and used as input to the model. Observed snowfall and snow-on-ground at the Coatesville 2 W NOAA meteorologic station were used for the snowfall and snowmelt simulation module (SNOW) and for calibration of the snow-module parameters. The days of snowfall and days that snow covered the ground at the Coatesville 2 W station for the years 1995-98 are listed in table 3. No snowfall occurred in the period October 1, 1994, through December 31, 1994. Snow accumulation and snowmelt had the most effect on streamflow in the year 1996. Snow was on the ground for all of January and 2 weeks of February 1996. In 1996 and 1997, snow cover of 2 in. or greater lasted no longer than 2 weeks.

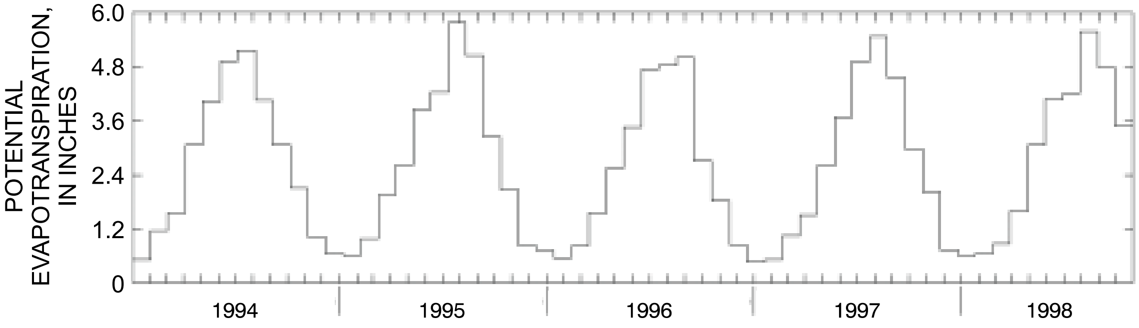

Figure 5. Monthly estimates of potential evapotranspiration for Wilmington Airport, Delaware, 1994-98.

Table 3. *Days of snowfall and snow-on-ground at the National Oceanic and Atmospheric Administration meteorologic station Coatesville 2 W, 1994-98*

Year	Days of snowfall (maximum in inches[1])	Days of snow on ground (maximum in inches[1])	Days of greater than 2 inches[1] of snow on ground
1994	27 (8.6)	72 (16)	69
1995	10 (9.1)	16 (10)	13
1996	27 (22.8)	52 (29)	39
1997	21 (11.4)	23 (11)	6
[2]1998	7 (1.4)	2 (1)	0

[1] Inches of snow, not inches of water equivalent.
[2] Through October 1998.

Simulation of stream water temperature requires air temperature, dewpoint, wind speed, cloud cover, and solar radiation. Hourly air temperature, dewpoint, wind speed, and cloud cover from the Wilmington, Del., Airport were used as input to the model. In the northern parts of the basin, air temperatures for input to the model were derived from data at the Coatesville 2 W NOAA meteorologic station. Minimum and maximum daily air temperatures for the Coatesville 2 W station were disaggregated to hourly air temperature with METCMP, using the Wilmington Airport hourly data. Hourly estimates of solar radiation for Wilmington, Del., were calculated by the Northeast Regional Climate Center based on a method described by DeGaetano and others (1993).

Water-Use Data

Simulation of streamflow and water quality requires information about stream withdrawals and discharges. Water withdrawal and discharge data were obtained from CCWRA, WRA at the University of Delaware, DNREC, and the Brandywine Valley Association who compiled water-use information from various sources including PADEP, DNREC, and individual water users. Many of these data were reported on a monthly or annual basis, and in many cases, were available for only 1, 2, or 3 years of the 1994-98 simulation period. Where at least 1 year of acceptable monthly withdrawal data were available, the remaining years' missing information was filled by copying data from the most recent year prior to the missing period. Where no monthly withdrawal data were available, missing monthly data were filled with values equal to 75 percent of permitted withdrawal maximums. Missing discharge data were filled using the same method as withdrawals.

The discharges and withdrawals included in the simulation are presented in table 4. Isolated single-family residential discharges were not included in the streamflow simulation. Monthly-to-hourly disaggregation of water-use data were done by the HSPF model at the time of simulation. Inputs from point sources include water-quality constituent loads, discharge temperature, and rate of discharge. Point-source discharge-quality data, typically available as monthly or yearly values, were disaggregated to an hourly time step by dividing monthly or yearly values by the number of time steps in those periods during simulation.

Table 4. *Stream withdrawals and discharges of flow and ammonia and phosphorus loads included in the Hydrological Simulation Program–Fortran (HSPF) model of the Red Clay Creek Basin, Pennsylvania and Delaware*

[Mgal/d, million gallons per day; lb/d, pounds per day; IND, industrial; IRR, irrigation; STP, sewage-treatment plant; NCW, non-contact cooling water; SRD, single residence discharge; --, not applicable or no information]

Subbasin	Name	Type	Flow volume (Mgal/d)		1994-98 average discharge load (lb/d)	
			Capacity or flow limit	1994-98 average	Ammonia	Phosphorus
		Withdrawals				
West Branch	J.H. Thompson, Inc.	IND	0.0004	0.0004	--	--
East Branch	Kennett Square Golf Course	IRR	--	.032	--	--
Main stem	NVF, Yorklyn	IND	2.25	2.07	--	--
Main stem	Hercules Research Center	IND	.675	.120	--	--
Main stem	Hercules Country Club	IRR	--	.050	--	--
Main stem	Samuel Beard	IND	.0225	.0226	--	--
		Discharges				
West Branch	New Bolton Center	STP	--	.022	0.122	0.331
West Branch	NVF, Kennett Square	NCW	.25	.264	.22	.203
West Branch	Kennett Square Borough - sewage treatment plant	STP	1.10	.901	38.1	13.82
East Branch	Sunny Dell Foods - PA001	STP	.05	.041	.507	.622
East Branch	Sunny Dell Foods - PA003	NCW	.09	.071	.059	.055
East Branch	East Marlborough	STP	.15	.087	.941	1.326
Main stem	Center for Creative Arts	STP	.0015	.0006	.007	.009
Burroughs Run	D'Ambro	SRD	.0005	.0004	.005	.006
Main stem	NVF, Yorklyn	NCW	2.17	1.69	1.41	1.295
Main stem	Greenville Country Club	STP	.015	.004	.047	.058
Main stem	Hercules Inc.	NCW	.35	.083	.069	.064
Main stem	Haveg/Amtek - 001[1]	NCW	.006	.0004	.0003	.0003
Main stem	Haveg/Amtek - 003[1]	NCW	.004	.002	.002	.002

[1] Eliminated July 1996.

Spatial Data

Spatial data input to the HSPF model are used primarily to define the structure and “fixed” characteristics of the model. The principal structural unit of the HSPF model is the hydrologic response unit (for example, PERLND and IMPLND). Hydrologic-response units for the modeled basin were determined from analysis of digital spatial data consisting of land use, elevation, geology, soil association, and sanitary-sewer service area data. The digital spatial data were compiled from multiple sources by the WRA for New Castle County for this study (Greig and others, 1998). These data were processed with a geographic information system (GIS) and compiled for model input. Non-digital data such as information regarding the location of specific agricultural practices also were used. Fifteen land-use categories were delineated in the original digital database. These categories were simplified and reclassified into 10 pervious and 2 impervious land-use categories that were expected to have distinct nonpoint-source water-quality responses (table 5). Digital spatial data showing impervious areas were not available and impervious areas were estimated as a percentage of selected pervious areas, as discussed later in a section on simulation of streamflow in this report. The spatial distribution of the simplified pervious land-use categories is shown in figure 6. Areas of undesignated land use were considered to have characteristics of areas with open land use.

Agricultural land use was divided into three characteristic subtypes for the model. Agricultural-livestock land use identifies small acreage farms (less than 100 acres) with high animals-per-acre densities, limited pasture areas, and rowcrops. Small acreage dairy operations typify this land-use type. Agricultural-rowcrop land use identifies farms with lower animals-per-acre densities (typically beef cattle and horses) and substantial pasture and crop acreage. Agricultural-mushroom land use is the third type of agricultural land use delimited. Mushroom growing, which involves the preparation and use of large amounts of manure-based compost, is more prevalent in the Red Clay Creek and adjacent White Clay Creek Basin than elsewhere in the Christina River Basin. Because digital data were not available to describe the spatial distribution of the three agricultural subtypes, the distribution of these land-use types were estimated as percentages of the general agricultural category based on knowledge of the watershed and information from CCCD.

Forested land is distributed throughout the basin and tends to be along stream channels, especially in the southern and northern parts of the basin (fig. 6). The largest amounts of forested land are in the upper West Branch Red Clay Creek and in the lower main stem near Hoopes Reservoir.

Table 5. *Land-use categories used in the Hydrological Simulation Program–Fortran model of the Red Clay Creek Basin, Pennsylvania and Delaware*

Land-use category for model		Description of land use
Pervious land area [1]	residential-septic	Includes all residential land not within a sewer service area
	residential-sewer	Includes all residential land within a sewer service area
	urban	Includes commercial, industrial, institutional, transportation uses
	agricultural-livestock	Predominantly mixed agricultural activities of dairy cows, row crop, pasture and other livestock operations
	agricultural-rowcrop	Predominantly row-crop cultivation (corn, soybean, alfalfa), may include some hay or pasture
	agricultural-mushroom	Mushroom growing activities including compost preparation, mushroom house operations, spent compost processing
	open	Recreational and other open land not used for agriculture
	forested	Predominantly forested land
	wetlands / water	Wetlands and open water
	undesignated	Land use not defined
Impervious land area[2]	residential	Impervious residential land
	urban	Impervious commercial, industrial, and other urban land

[1] Pervious land area is designated as PERLND in model.

[2] Impervious land area is designated as IMPLND in model.

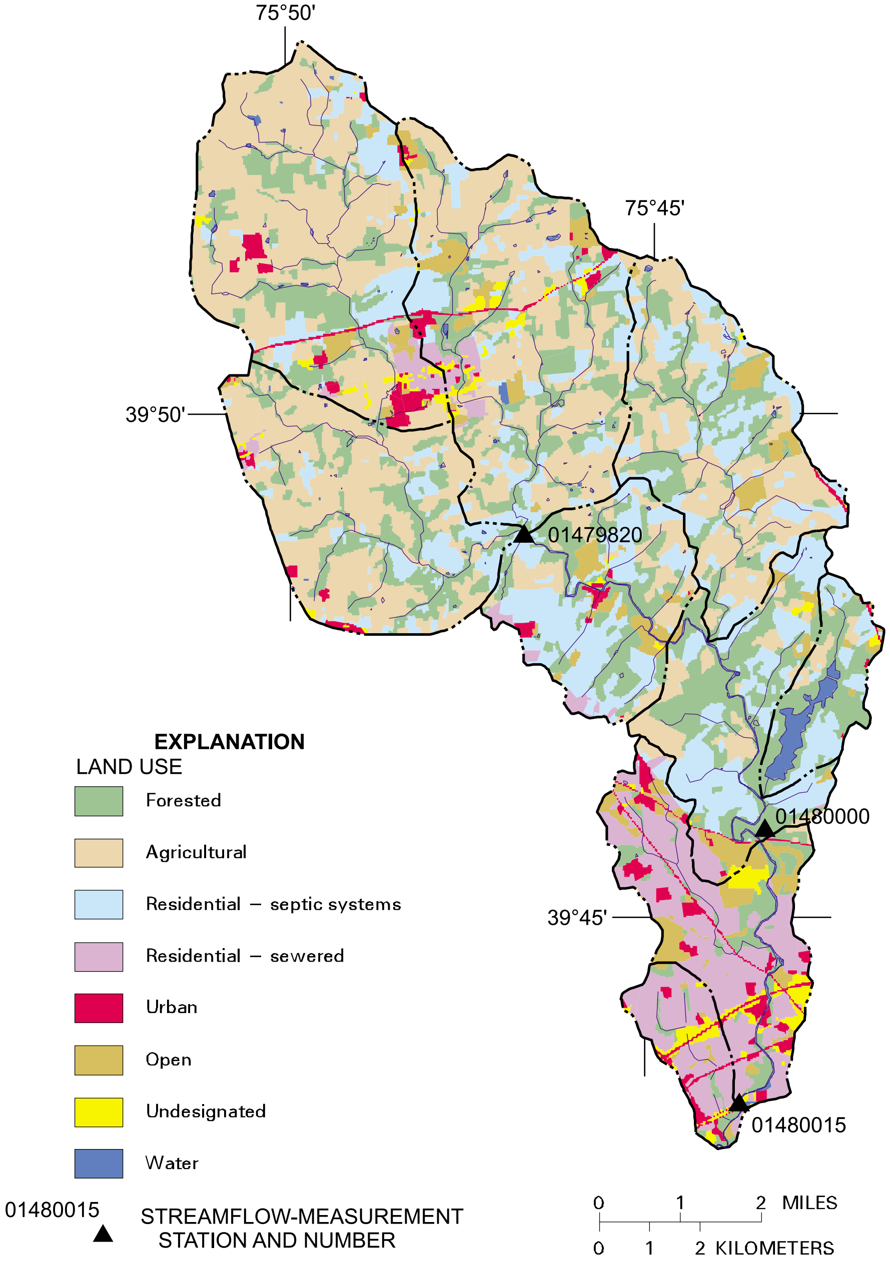

Figure 6. Generalized 1995 land-use map for the Red Clay Creek Basin, Pennsylvania and Delaware.

Residential land use is distributed throughout the basin and is divided into two types: sewered and non-sewered. Sewered residential areas tend to have higher housing densities and are nearer to urban / suburban areas than non-sewered area. Non-sewered residential areas tend to have lower densities and are more rural. Urban land use in the basin generally is concentrated in the southern tip of the basin and in areas underlain by carbonate rocks centered on Kennett Square, Pa. Other urban land use is in small boroughs and towns and along major roadways.

Model-Calibration Data

Observed streamflow and water-quality data are needed to calibrate the hydrologic and water-quality components of the HSPF model, respectively. These data are available at streamflow-measurement stations (gages) and water-quality monitoring sites established in the basin for this study and for other purposes. The period of record and frequency of observations differ among these gages and monitoring locations. In general, fewer water-quality data are available than streamflow data.

Hydrologic Data

Data used for the hydrologic calibration were collected at three USGS streamflow-measurement stations operating in the Red Clay Creek Basin during the 1994-98 simulation period (table 6; fig. 7) (Durlin, 1995; Durlin and Schaffstall, 1997a, 1997b, 1998, 1999; James and others, 1996, 1997, 1998, 1999).

Streamflow data at all the sites were recorded at time steps smaller than the 1-hour time step used in model simulations. Because of the shorter time steps, no disaggregation was needed for the streamflow data. However, periods of missing data and periods of poor-quality data because of freezing conditions are numerous in the hourly streamflow record. Periods of missing data were estimated by interpolation or regression. During periods of relatively steady base flow, missing data were interpolated. During periods of rapidly changing flow (generally stormflow), missing data were estimated by linear regression. A regression equation was generated using data from the nearest upstream or downstream streamflow-measurement station, and which bounded the period of missing record. Poor-quality data, because of freezing conditions, were more problematic in that data from nearby stations also usually were affected. As a result, these data were used as recorded unless data of better quality were available from a nearby streamflow-measurement station.

Table 6. *Streamflow-measurement stations in the Red Clay Creek Basin, Pennsylvania and Delaware*

U.S. Geological Survey station identification number	Station name	Drainage area (square miles)	Period of record
01479820	Red Clay Creek near Kennett Square, Pa.	28.3	1 / 88 - current
01480000	Red Clay Creek at Wooddale, Del.	47.0	4 / 43 - current
01480015	Red Clay Creek near Stanton, Del.	[1] 52.4	10 / 88- current

[1] Area determined by analysis of digital spatial data was 50.2 square miles.

Water-Quality Data

Water-quality data at stream-monitoring sites were used in model calibration. Water-quality data for the simulation period 1994-98 were collected by PADEP, DNREC, and USGS as part of various monitoring efforts in the Red Clay Creek Basin (fig. 7). The period of record at monitoring sites varied from 1 to 5 or more years, and the sampling interval varied from hourly or less for storms to annually (table 7). The chemical analyses of samples collected as part of these monitoring efforts varied. Other water-quality data used for assessing model calibration include annual base-flow nutrients data at two sites sampled by USGS as part of the stream conditions of Chester County biological monitoring program.

Two of the monitoring programs were designed specifically to assist in the current assessment of water quality in the Red Clay Creek: (1) monthly and bi-monthly monitoring efforts were conducted by DNREC and PADEP from 1995 to 1998; and (2) a hydrologically based sampling scheme for nonpoint-source monitoring was done by USGS, PADEP, and DNREC in 1998. The monthly and bi-monthly monitoring effort included analyses for metals, nutrients, suspended solids, and other constituents in samples collected at five stream sites in the Red Clay Creek Basin and was done to support an assessment of water quality during low-flow conditions and target point-source contributions. The hydrologically based

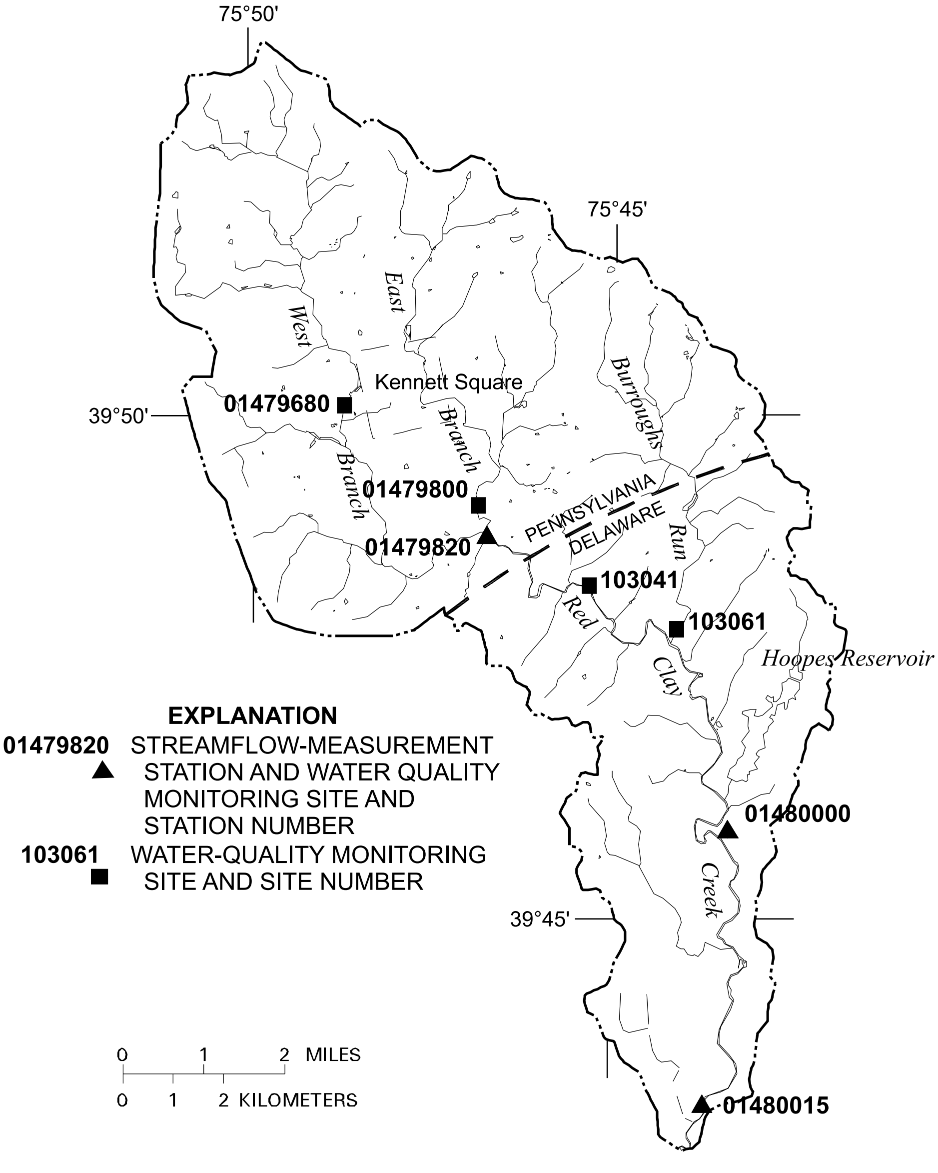

Figure 7. Location of streamflow-measurement stations and water-quality monitoring sites in the Red Clay Creek Basin, Pennsylvania and Delaware.

Table 7. *Water-quality monitoring sites in the Red Clay Creek Basin, Pennsylvania and Delaware, during 1994-98*

[--, no data; P, Pennsylvania Department of Environmental Protection; D, Delaware Department of Natural Resources and Environmental Control; U, U.S. Geological Survey; TSS, total suspended solids]

U.S. Geological Survey station identification number	State site number	Drainage area (square miles)	Location (predominant land use)	Monitoring agency	Period of record	Chemical analyses
Monthly and bi-monthly monitoring sites						
01479820	WQN150	28.3	Red Clay Creek near Kennett Square, Pa.	P	1995-98	Nutrients, TSS
--	103041		Red Clay Creek at Road 258A in Ashland, Del.	D	1995-98	Nutrients, TSS
--	103061		Burroughs Run, Rt. 241 at bridge, Del.	D	1995-98	Nutrients, TSS
01480000	103031	47.0	Red Clay Creek, Rt. 48 at Wooddale, Del.	D	1995-98	Nutrients, TSS
01480015	103011	52.4	Red Clay Creek, Rt. 4 at Stanton bridge, Del.	D	1995-98	Nutrients, TSS
Base flow and stormflow nonpoint-source monitoring small and whole basin sites						
01480000	--	45.0	Red Clay Creek at Wooddale, Del. (mixed-whole basin)	U, P, D	1998	Nutrients, TSS
Annual biological monitoring sites						
01479680	--		West Branch Red Clay Creek at Kennett Square, Pa.	U	1971-97	Nutrients
01479800	--		East Branch Red Clay Creek near Five Points, Pa.	U	1970-current	Nutrients

sampling scheme included analyses for nutrients, suspended solids, and organic carbon at 1 site in the Red Clay Creek Basin and 10 sites elsewhere in the Christina River Basin and was done to support an assessment of these constituents under base-flow and stormflow conditions throughout the year and assist in the evaluation of nonpoint-source contributions to the stream.

The nonpoint-source water-quality monitoring in 1997-98 in the Christina River Basin was designed to provide data on the concentrations and loads of nutrients and suspended solids seasonally under various hydrologic conditions for the whole of each of the four subbasins and for seven small areas predominantly covered by one land use. Samples were collected during four base-flow periods and up to six stormflow events. Continuous data collected at the nonpoint-source monitoring sites included streamflow and water temperature. In the Red Clay Creek Basin, samples collected at the Red Clay Creek at Wooddale, Del., site (01480000) provided information about the water quality of the whole basin (about 85 percent of the drainage area). Samples collected in the seven small subbasins predominantly covered by one land use (table 1) elsewhere in the Christina River Basin were used to provide information about the relation between land use and water quality. The predominant land uses in the small-basin sites include various types of agricultural, residential, forested, and urban land use. The small-basin data were used to develop model parameters for specific land uses. The parameters developed for specific land uses may be transferred to simulate water-quality response of those land uses throughout the modeled area.

The stormflow and base-flow sampling periods were selected as representative of the range of seasonal, hydrologic, and land-use conditions in the basin. Timing for the six stormflow events was as follows: two storms in mid to late winter (February 4-5, and March 8-9, 1998), one storm in early spring after pre-planting tillage (May 2-3, 1998), one storm in late spring / early summer after planting of crops (June 12-13, 1998), one storm in midsummer (July 8-9, 1998), and one storm in fall after harvest (October 8-9, 1998). Sampling was delayed because of dry conditions in the fall of 1997. Because of logistical problems, no samples were collected for the February 1998 storm at Red Clay Creek at Wooddale. In addition, because of the mild winter of 1998, there was no opportunity to collect samples from frozen-ground runoff and snow-melt events. Sampled storms resulted from precipitation events that ranged from about 0.4 to 3.3 in. For Brandywine Creek at Chadds Ford, Pa., these precipitation events resulted in peak flows with a 1-year or less recurrence interval. Base flow was sampled in January, April, July, and September 1998.

Base-flow and stormflow samples collected from January to October 1998 were analyzed for concentrations of dissolved and total nitrogen and phosphorus species and suspended solids (table 8). Other constituents, such as dissolved organic carbon (DOC) and chlorophyll *a*, and properties, such as chemical oxygen demand (COD) and biological oxygen demand (BOD), also were analyzed to better understand and simulate the chemical processes involving the fate and transport of nutrients. Chloride was measured to provide data on the

Table 8. *Constituents in nonpoint-source monitoring samples to be determined by laboratory chemical analysis[1], Red Clay Creek Basin, Pennsylvania and Delaware*

[mg/L, milligrams per liter; EPA, U.S. Environmental Protection Agency; STDMTD, Standard Methods (American Public Health Association, 1995); µS/cm, microsiemens per centimeter]

Constituent	STORET code	Method	Reporting limit (mg/L except where noted)
Required constituents or properties for all samples			
Ammonia nitrogen, dissolved	00608	EPA 350.1	0.004
Ammonia nitrogen, total	00610		.004
Kjehldahl nitrogen, dissolved	00623	EPA 351.2	.05
Kjehldahl nitrogen, total	00625		.05
Nitrite plus nitrate nitrogen, dissolved	00631	EPA 353.2	.05
Orthophosphorus, dissolved	00671	EPA 365.1	.005
Phosphorus, dissolved	00666	EPA 365.1	.005
Phosphorus, total	00665		.005
Chloride	00940	EPA 325.2	1
Specific conductance	90095	EPA 120.1	1 µS/cm
Total suspended solids-concentration	80154	EPA 160.2	1
Biological oxygen demand (BOD$_{20}$)	00308	EPA 405.1	2.4
Dissolved organic carbon	00681	EPA 415.1	1
Chlorophyll-a[2]	70953	92 STDMTD	.001
Pheophytin		10200H	.002
Additional constituents-Mainstem site at Red Clay Creek at Wooddale, Del.			
Copper, dissolved	01040	EPA 220.2	.005
Copper, total	01042		.005
Lead, dissolved	01049	EPA 239.2	.003
Lead, total	01052		.003
Zinc, dissolved	01090	EPA 200.7	.010
Zinc, total	01092		.010
Chemical oxygen demand	00340	EPA 410.1, 410.2, 410.3	5.0
Total organic carbon	00680	EPA 415.1	1

[1] Specifications for analytical method, reporting limit, holding time, sample volume and preservation provided by the Delaware Department of Natural Resources and Environmental Control laboratory.

[2] First storm sampling event, all grab sampling events.

concentrations of a conservative solute. Stormflow samples were collected by USGS and the University of Delaware. Base-flow samples were collected by PADEP and by DNREC. DNREC's laboratory in Dover, Del., performed all laboratory chemical analyses. Results of laboratory analyses for all stormflow and base-flow samples are listed in appendix 1.

Two types of samples, discrete and composite, were collected by an automatic sampler during storm events. Discrete samples, collected at fixed-time intervals during the storm event, represent instantaneous concentrations. Composite samples can be used to estimate loads for a storm event. The automatic sampler was programmed prior to each storm event to start sampling at a pre-determined change in stage, and collect one series of fixed-interval discrete samples and another series of flow-weighted aliquots (250 mL each) for the composite sample. The fixed-interval series consisted of up to six 2-L samples, collected from 1.5 to 3 hours apart. The flow-weighted series consisted of up to 48 250-mL samples. The intake for the automatic sampler was set in mid stream and stage was determined by a transducer set in the stilling well and linked to the automatic sampler. Streams were assumed to be well mixed. The automatic sampler was programmed to collect a sample at fixed-time intervals and after each time that a pre-determined flow volume, calculated using an established rating between stage and streamflow, had passed by the monitoring site. Composite samples were obtained by mixing the series of flow-weighted aliquots. Because the automatic sampler was programmed in advance of storms for which the intensity and duration were unknown, the extent of the actual storm periods covered by samples varied.

The measured concentration of constituents in discrete storm samples was, in general, related to streamflow (fig. 8). The concentration of total suspended solids, total ammonia nitrogen plus organic-nitrogen, and total phosphorus tended to increase with increasing streamflow whereas the concentration of dissolved nitrite plus nitrate nitrogen, dissolved ammonia nitrogen, and dissolved orthophosphate tended to decrease with increasing streamflow.

Concentrations of suspended solids and nutrients in stream samples differed at the Wooddale monitoring location in relation to hydrologic conditions. The distribution of constituent concentrations at the Wooddale nonpoint-source monitoring site under stormflow and base-flow conditions are shown in figures 9 and 10. Concentrations of total suspended solids, total ammonia plus organic nitrogen, and total phosphorus in stream samples are greater under stormflow conditions than under base-flow conditions. Concentrations of dissolved nitrate in stream samples are greater under base-flow conditions than under stormflow conditions (fig. 9). Concentrations of dissolved and total ammonia tend to be slightly greater under stormflow conditions than base-flow conditions. Concentrations of dissolved orthophosphate in stream samples tend to be slightly greater under base-flow conditions than under stormflow conditions, but conversely, concentrations of total phosphorus are greater under stormflow conditions than base-flow conditions (fig. 10). Base-flow concentrations are controlled primarily by ground-water discharge and stormflow concentrations by runoff and interflow processes.

Elsewhere in the Christina River Basin, differences in water quality may be related to land use. Data from 1998 (Senior and Koerkle, 2003a, 2003b) indicate that under stormflow conditions, concentrations of suspended solids, nitrate, ammonia, dissolved orthophosphate, and total phosphorus generally were higher at the sites in predominantly agricultural subbasins than at sites in subbasins with predominantly residential or forested land uses with a few exceptions. Concentrations of dissolved nitrate and orthophosphate under base-flow conditions also commonly were higher at the two sites in predominantly agricultural subbasins than at sites in subbasins with other land uses. Concentrations of suspended sediment, nitrate, and total phosphorus under base-flow and stormflow conditions were greater at the site in the predominantly non-sewered residential subbasin than at the sites in the predominantly forested and sewered residential subbasins. Although elevated ammonia and orthophosphate can be related to the land use, some of these constituents may be associated with discharge from sewage-treatment plants or other point sources upstream of monitoring sites.

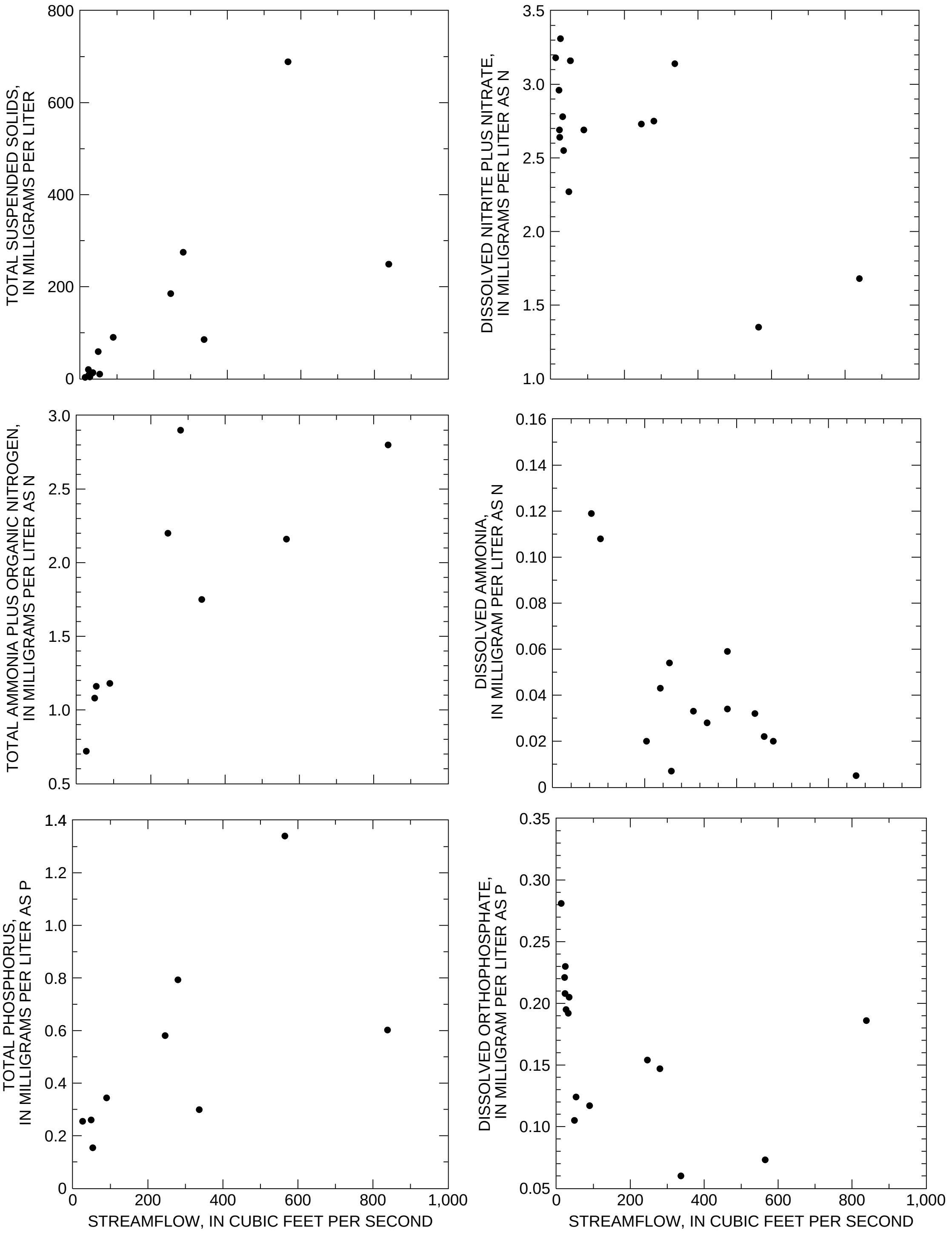

Figure 8. Relation between water-quality constituents and streamflow for stormflow and base-flow samples collected in 1998 at streamflow-measurement station 01480000, Red Clay Creek at Wooddale, Del.

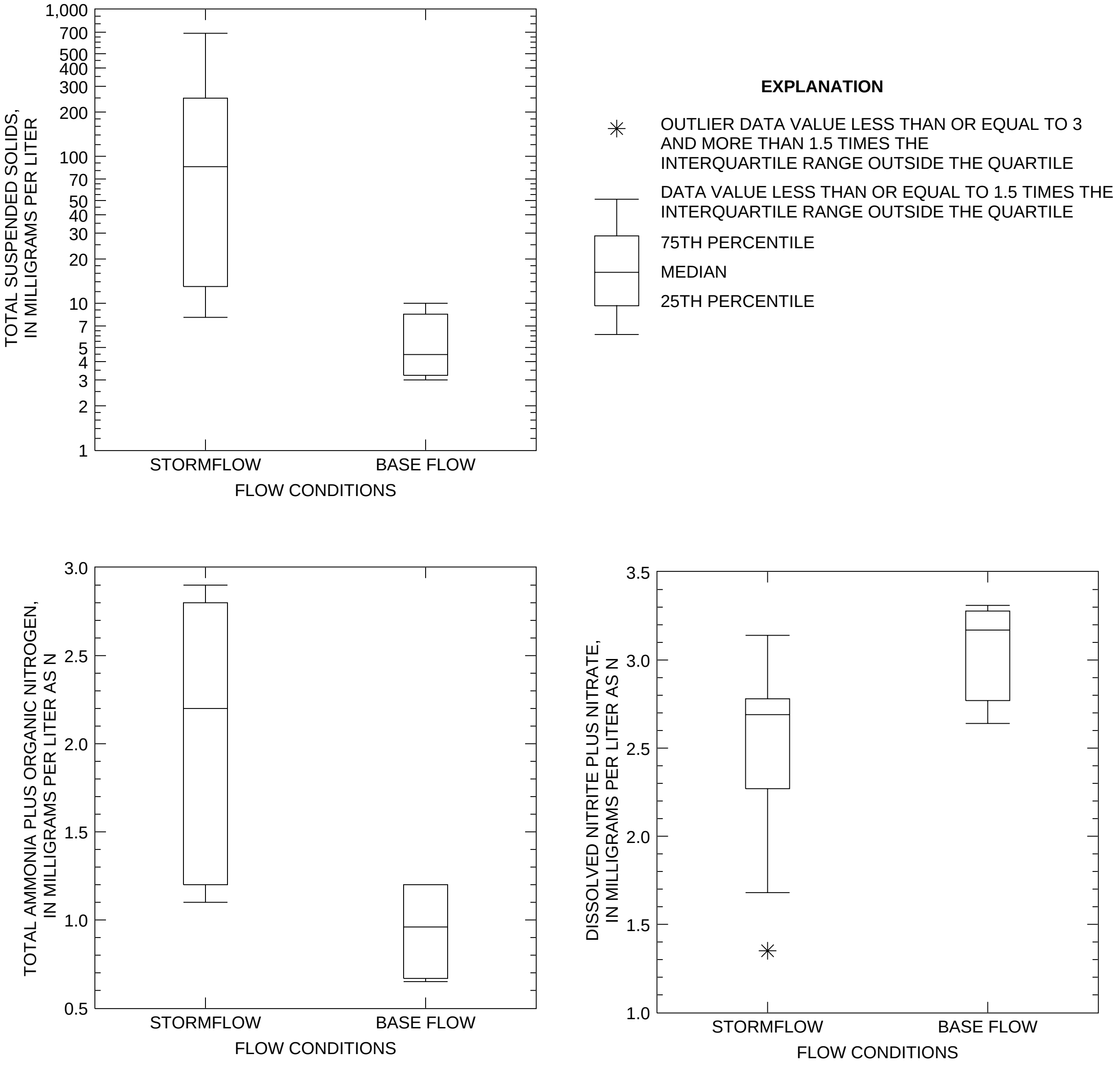

Figure 9. Distribution of concentrations of suspended solids, total ammonia plus organic nitrogen, and dissolved nitrate in samples collected under stormflow and base-flow conditions at the monitoring site, 01480000 Red Clay Creek at Wooddale, Del., 1998. (See figure 7 for location of and table 7 for description of monitoring site.)

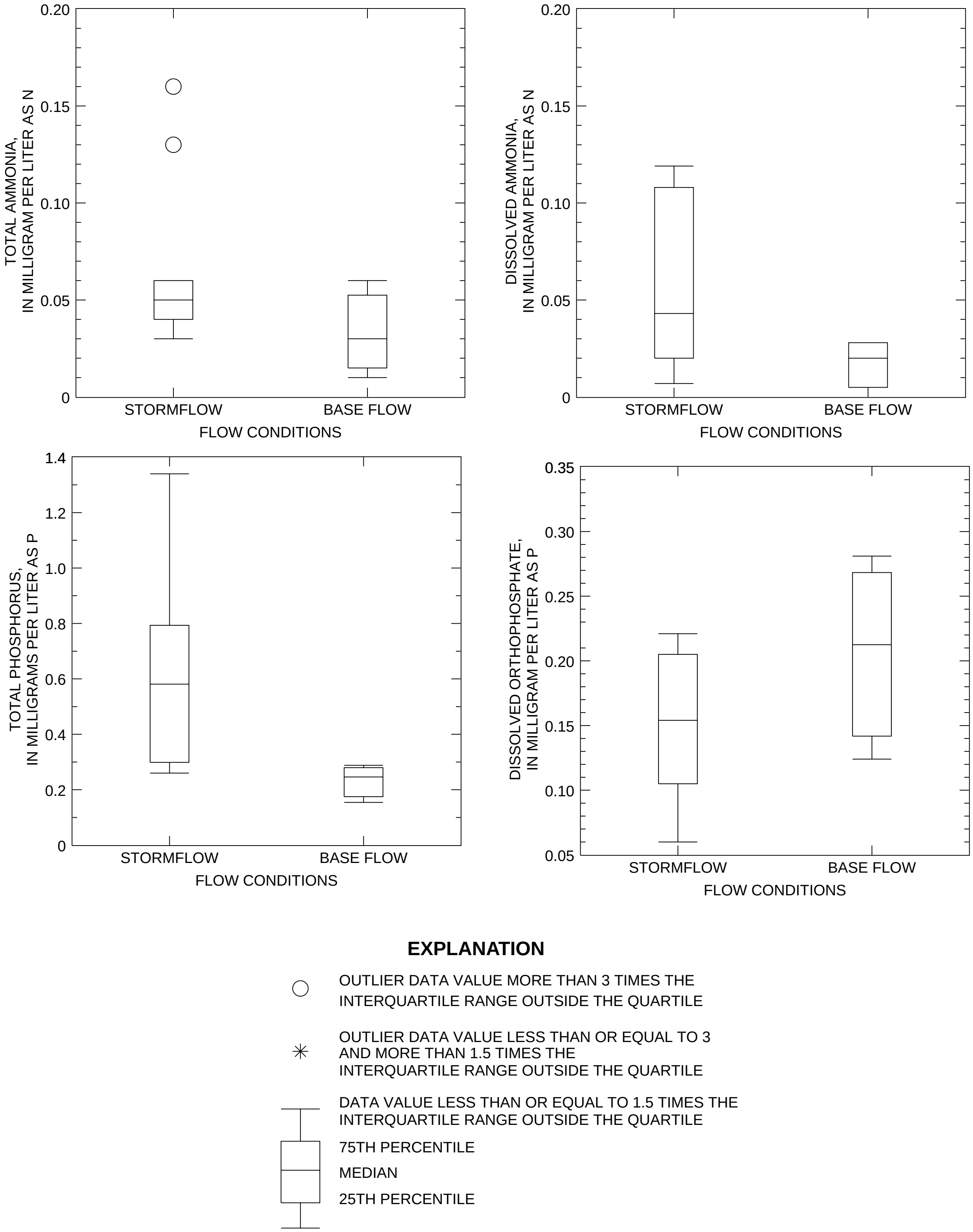

Figure 10. Distribution of concentrations of dissolved and total ammonia, dissolved orthophosphate, and total phosphorus in samples collected under stormflow and base-flow conditions at the monitoring site, 01480000 Red Clay Creek at Wooddale, Del.,1998. (See figure 7 for location of and table 7 for description of monitoring site.)

SIMULATION OF STREAMFLOW

Streamflow in the Red Clay Creek Basin was simulated for the period October 1, 1994, through October 29, 1998, or just over 4 years. Donigian and others (1984) suggest a 3-year to 5-year simulation period as optimal for HSPF because a greater variety of climatic conditions will be included.

The Red Clay Creek Basin was divided into three segments for the model (fig. 11). Segments of the basin area were defined primarily on the basis of spatial distribution of land use and soils. Within each segment, the hydrologic response of land areas was assumed to differ principally by land use because soils within each segment were similar. All model segments (fig. 11) receive precipitation input from the Porter Reservoir NOAA gage (fig. 3). The land-based hydrologic response in each segment was characterized spatially by subdividing the area into as many as 12 land-use categories consisting of 10 pervious and 2 impervious land-use types (table 9). These simplified land-use categories represent the predominant land uses in the Christina River Basin. Initial hydrologic-response parameters were assigned to the land-use categories and were modified as needed during model calibration. Parameters do not vary within a segment but may vary from segment to segment.

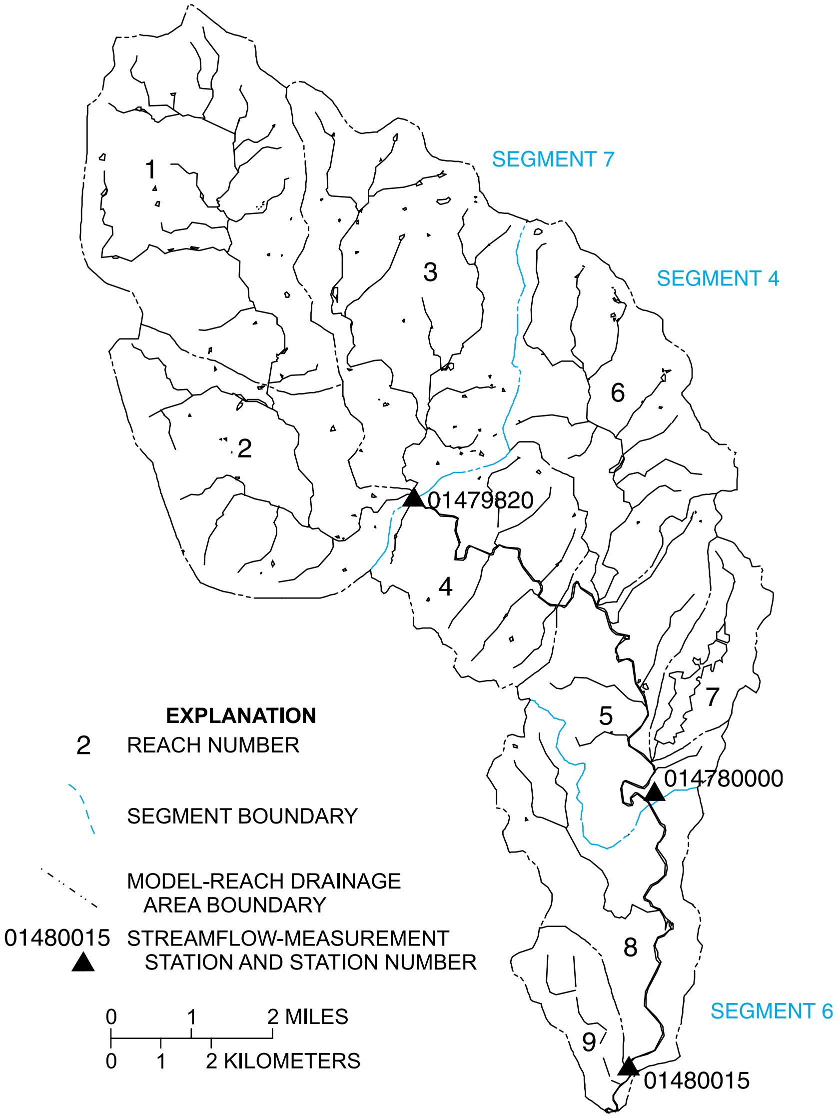

Figure 11. Location of segments, model-reach drainage area, and stream reaches (RCHRES) delineated for HSPF model of the Red Clay Creek Basin, Pennsylvania and Delaware.

Table 9. *Reach number, length, drainage area, segment number, and percent of land-use category in reach-drainage areas for Red Clay Creek model, Pennsylvania and Delaware*

[mi, miles; mi^2, square miles]

				Land-use category (percent of drainage area)											
Segment number	**Reach number**	**Reach length (mi)**	**Reach drainage area (mi^2)**	**Residential - septic**	**Residential- sewer**	**Urban**	**Agricultural - livestock**	**Agricultural - row crop**	**Agricultural - mushroom**	**Forested**	**Open**	**Wetland.water**	**Undesignated**	**Impervious - residential**	**Impervious - urban**
7	1	5.00	10.08	10.4	1.6	2.1	5.9	46.8	5.9	18.4	2.8	0.4	1.6	1.9	2.2
7	2	4.90	7.39	11.8	.5	.7	0	40.9	17.5	25.2	.3	.2	.7	1.5	.7
7	3	7.20	9.90	14.9	1.9	1.0	0	33.1	14.2	22.5	5.8	.6	2.3	2.5	1.1
4	4	3.40	5.11	35.5	2.3	1.0	1.8	14.2	1.8	28.4	7.9	.8	.6	4.9	1.0
4	5	5.10	5.24	32.2	2.2	.2	0	14.6	0	37.7	6.0	1.2	.9	4.6	.2
4	6	5.00	7.10	23.9	0	.2	0	42.4	0	25.1	5.1	.1	.3	2.7	.2
4	7	1.70	2.10	26.1	0	.5	0	7.2	0	44.4	3.0	14.3	1.1	2.9	.5
6	8	4.30	5.38	1.5	35.3	5.3	0	1.6	0	13.4	13.8	1.4	6.3	15.3	6.0
6	9	.84	1.72	0	45.5	4.8	0	0	0	10.2	3.8	.4	9.9	19.5	5.9
All	Total	37.44	54.02	17.1	6.1	1.6	1.3	29.2	6.3	24.0	5.2	1.2	2.0	4.5	1.7

The amount of impervious land was calculated from the residential and urban pervious land uses using factors modified from WRA for New Castle County values in Greig and others (1998). Because the HSPF model simulates no infiltration in impervious areas and some runoff from impervious areas such as roofs and roads does infiltrate, the amount of effectively impervious area is expected to be lower than impervious areas estimated by land-use maps. Thus, the amount of effectively impervious area was reduced from the amount of impervious area estimated from land-use maps. This type of modification has been applied in HSPF models in other study areas (Zarriello, 1999). The proportion of effectively impervious land was estimated as 10 percent in residential areas without sewers, 30 percent in residential areas with sewers, 50 percent for urban areas. and 10 percent for undesignated lands in sewered areas.

Nine RCHRES were specified for the Red Clay Creek model (fig. 11). RCHRES lengths ranged from 0.84 to 7.20 mi in length; the median length was 5.0 mi. Selection of RCHRES lengths was guided by the confluences of major tributaries, the location of calibration points, the location of dams and impoundments, and major changes in land use contributing to a stream reach. Reach lengths were taken from topographic maps. Two RCHRES are in the West Branch, one RCHRES in the East Branch, and six in the main stem and tributaries below the confluence of the East and West Branches. The one reservoir in the basin, Hoopes Reservoir, was designated a reach but was not simulated in the model because negligible amounts of water are released from Hoopes Reservoir to Red Clay Creek except during periods of extreme low flow. The area draining directly to each reach ranged from 1.72 to 10.08 mi^2, with differing amounts of the various land-use categories in each reach drainage area (table 9).

Snowfall, snow accumulation, and snow melt were simulated throughout the basin because hydrologic and meteorologic records indicated substantial snow, ice, and sub-freezing temperatures during the winter of 1995-96. In the coldest periods, sub-freezing temperatures resulted in stream channel icing at the calibration sites. During the 1995-96 winter, only estimated daily streamflows were available during much of December, January, and February. Hourly streamflow values for these periods are considered poor and published daily streamflows are reported as estimated. Final calibration included the simulation of snow.

Assumptions

The simulation of streamflow in Red Clay Creek was done under the following assumptions: (1) inputs of hourly precipitation would be estimated reasonably well by disaggregated 24-hour precipitation data; (2) the average precipitation over a given land segment would be represented adequately by weighted data from a single precipitation gage; (3) a simplified set of PERLNDs and IMPLNDs would not unduly limit a satisfactory hydrologic calibration of the Red Clay Creek model.

Calibration

The basin hydrology model was calibrated using HSPEXP (Lumb and others, 1994), a computer program that assists in calibration using an expert system, and the calibration guidelines in Donigian and others (1984). The model-calibration effort was directed at the full range of observed streamflow with an emphasis on higher streamflows, because transport of many nonpoint source constituents is greatest at high flows. Prior to calibration, initial estimates of the hydrologic calibration parameters were determined. The initial values were derived from known watershed characteristics where possible, from parameters determined for calibrated HSPF models for the adjacent Brandywine and White Clay Creek Basins (Senior and Koerkle, 2003a, 2003b), from the HSPFParm database (Donigian and others, 1998), and from published sources such as Donigian and Davis (1978) and the U.S. Environmental Protection Agency Office of Water (2000b). During calibration with HSPEXP, simulated streamflow is compared to observed streamflow through statistical and graphical methods and suggestions are given as to which parameter(s) needs modification. HSPEXP also includes default criteria for determination of a satisfactory hydrologic calibration (table 10). The criteria are maximum allowable differences (errors) between observed and simulated streamflow expressed as percent error. These criteria are not fixed in HSPEXP and can be modified depending on the users' needs. Donigian and others (1984) offer the following error criteria for calibration: annual and monthly values less than 10-percent difference (Very Good); 10- to 15-percent difference (Good); 15- to 25-percent difference (Fair). Calibrated hydrologic parameter values are listed in the Brandywine UCI in appendix 2.

The model was calibrated at gaged locations along the main stem of Red Clay Creek in downstream order. For example, the part of the basin above Red Clay Creek at Kennett Square, Pa., (01479820) was calibrated before the part of the basin draining to the next gage downstream, Red Clay Creek at Wooddale, Del. (01480000). The period of calibration was October 1, 1994, through October 29, 1998.

Stormflow hydrograph calibration consisted of comparing stormflow volume, average simulated peak flows, and recession rates of selected storms with observed data in HSPEXP and visual examination of simulated and observed stormflow hydrographs. Thirty-six storm events were selected from the simulation period. Storms were

Table 10. *Calibration criteria and errors for Hydrological Simulation Program-Fortran (HSPF) simulated streamflow at three gaging sites in the Red Clay Creek Basin, for the period October 1, 1994, through October 29, 1998*

Calibration site[1]	Calibration criteria, in percent[2]						
	Total volume	Low-flow recession rate	50-percent lowest flows	10-percent highest flows	Storm peaks	Seasonal volume error	Summer storm volume error
	10.0	0.03	10.0	15.0	20.0	30.0	50.0
	Calibration errors from HSPEXP, in percent						
01479820	-0.4	0	1.0	0.4	-13.6	7.6	-8.9
01480000	2.1	0	2.7	4.5	-5.4	6.4	-13.9
01480015	-.8	-.01	-3.8	2.3	-6.2	3.4	-9.9

[1] Streamflow-measurement station number.

[2] Default criteria for satisfactory hydrologic calibration in HSPEXP.

selected using the following criteria as a guide: (1) total storm precipitation will be equal to 1 in. or more and cover a broad area of the drainage basin in order that all / most segments of the basin exhibit a hydrologic response to the storm; and (2) all storms during which water-quality data were collected. The summary statistics: error in total storm volume, error in the mean of peak stormflows for all selected storms, and error in total summer storm volume were calculated for the 36 selected stormflow periods collectively. For all three Red Clay Creek sites, these statistics indicate simulation errors less than the default HSPEXP error criteria (table 10). However, these statistics are not indicative of the errors for individual storm simulations. Examples of individual stormflow hydrographs for selected storms in 1998 are presented in the section “Simulation of Water Quality.”

In general, errors in individual storm simulations vary widely. The largest errors in the simulation of stormflow appear to result from incorrectly specified precipitation. Typically, a time discrepancy between the simulated and observed stormflow hydrographs has no effect on the HSPEXP error statistics except when the time shift moves the simulated hydrograph beyond the established storm-event time boundaries. These boundaries are set at whole day increments (for individual storms) or seasonal periods (June, July, August for the summer). However, a time-shifted event can cause difficulties with water-quality calibrations; a temporal mismatch between observed and simulated streamflows produces a corresponding mismatch between observed and simulated water quality. Use of weighting of rainfall also has the potential to result in incorrectly specified rainfall for individual storm events. Stormflow simulations with the least error tended to result from storms that produced the most uniform rainfall distribution across a drainage basin. In the HSPF model for the adjacent Brandywine Creek Basin, errors in individual storm simulations tended to increase with decreasing drainage area (Senior and Koerkle, 2003a).

Time-series comparison of simulated and observed daily mean streamflow at the three streamflow-measurement stations on Red Clay Creek, 01479820 near Kennett Square, 01480000 at Wooddale, and 01480015 near Stanton, (fig. 12) indicate no strong temporal pattern in errors except during low-flow conditions in 1995. From July to September 1995, simulated streamflow exceeds observed streamflow for the near Kennett Square station and is less than observed streamflow for the other two streamflow-measurement stations downstream in Delaware. An unquantified diversion (private property owner periodically diverts some streamflow into mill race) at the streamflow-measurement station at Kennett Square commonly results in reduced apparent streamflow at that station. This reduction in measured streamflow is greatest under low-flow conditions.

Time series comparison of simulated and observed hourly streamflow at the nonpoint-source water-quality monitoring site, Red Clay Creek at Wooddale, are shown in figure 13 for the sampling period January 1 through October 29, 1998. Simulated low-flow conditions tend to exceed observed streamflow in the winter and summer months of 1998. In 1998, most of the larger storms (greater than 100 ft^3/s) are undersimulated, with the exception of a storm in late January and another in late May. Observed and simulated storms in the winter of 1998 tend to be larger in magnitude than later in the year.

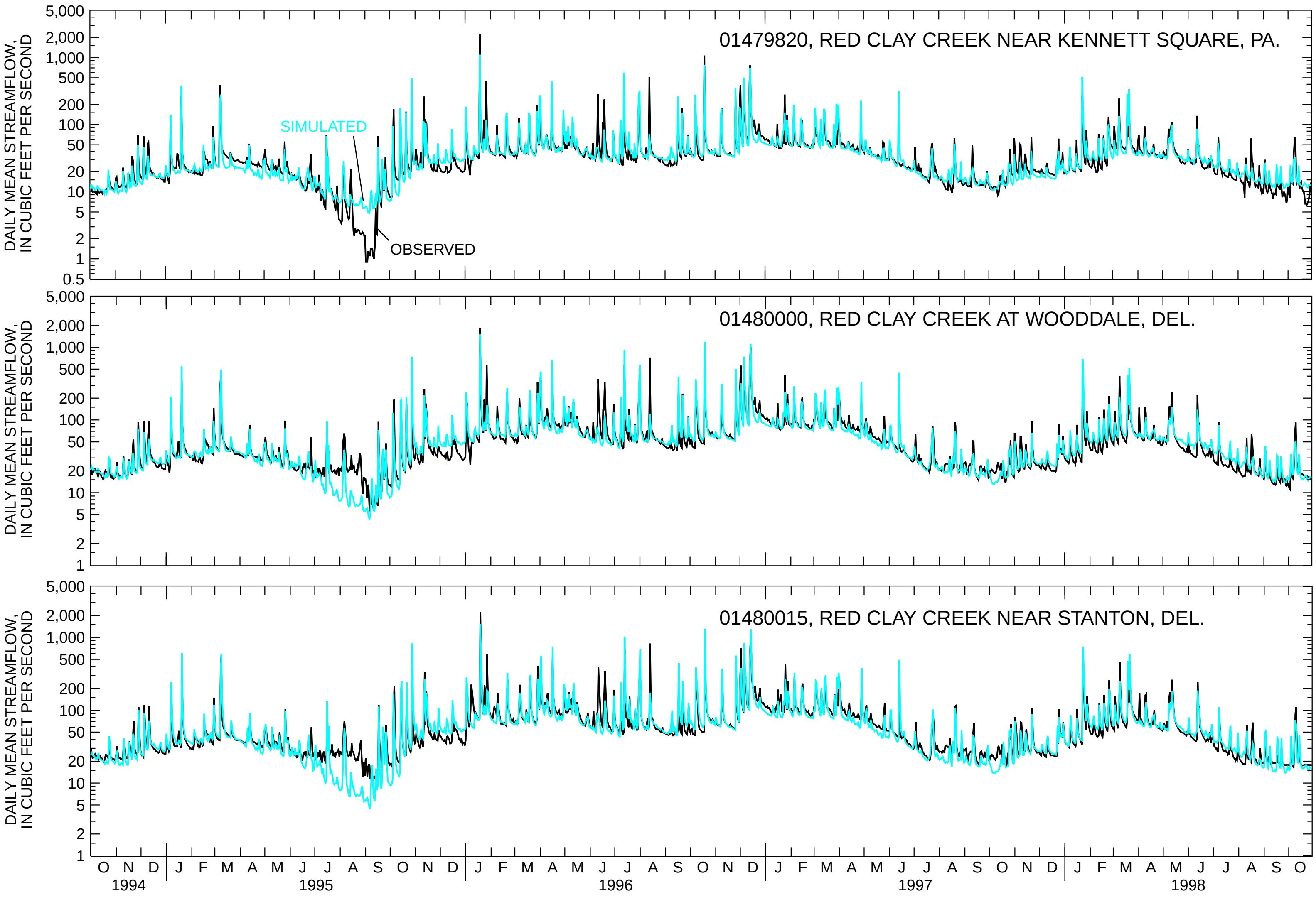

Figure 12. Simulated and observed daily mean streamflow at three streamflow-measurement stations in the Red Clay Creek Basin, Pennsylvania and Delaware, for the period October 1, 1994, through October 29, 1998.

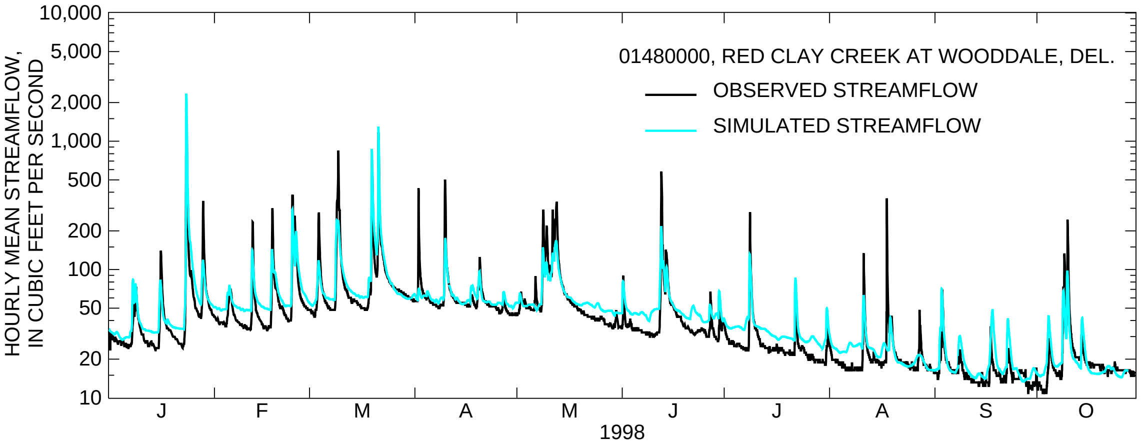

Figure 13. Simulated and observed streamflow at the nonpoint-source water-quality monitoring site in the Red Clay Creek Basin, Pennsylvania and Delaware, for the sampling period January 1 through October 29, 1998.

Flow-duration curves of simulated and observed hourly streamflow for the streamflow sites on the main branch of Red Clay Creek generally indicate good agreement, except for the lowest observed flows (fig. 14). Overall, the simulated durations of the highest flows, those that transport the bulk of nonpoint-source constituents, agree with observed high flow durations, except for the highest 0.1 percent of flows at the Kennett Square site.

The model performance in simulating hourly and daily streamflow was evaluated at the one nonpoint-source water-quality monitoring sites for 1998, the year of stormflow and base-flow water-quality data collection, and at three sites for the calibration period of 1994-98. Statistical measures of the hourly and daily streamflow comparison are listed in table 11. Correlation and model-fit efficiency coefficients for the most-upstream site (Red Clay Creek near Kennett Square) are lower than those for the sites downstream (Wooddale and Stanton). Unlike the flow-duration comparisons, the statistics for one-to-one comparison of observed and simulated values (table 11) are affected by errors in the timing of storms. Because errors in the timing of precipitation and consequent storms commonly occur in shifts on the order of hours, not days, they result in lower values of correlation and model-fit efficiency coefficients for hourly streamflow compared to those for daily streamflow (table 11). Errors in timing of precipitation on the order of hours affect simulated stormflow in small drainage areas to a greater extent than simulated stormflow in large drainage areas because the time to peak for storms generally increases with basin size. The evaluation indicates that the model-fit efficiency and correlation coefficients at Wooddale are similar and generally slightly better for the calibration period of 1994-98 than for 1998. Model-fit efficiency coefficients greater than 0.97 indicate an excellent calibration (Martin and others, 2000; James and Burgess, 1982).

Simulated and observed streamflow, in inches, for Red Clay Creek near Stanton, Del., is listed by year and for the entire 4-year period of simulation in table 12. A plot of cumulative errors for Red Clay Creek near Stanton, Del. (fig. 15), shows that large changes in cumulative error occur during the winters of 1995-96 and 1996-97 and the summers of 1995 and 1996. During the winter of 1996-97, snowfall accumulation and snowmelt were important processes. The winter periods were oversimulated and the summer periods were undersimulated.

Water in an HSPF model reach can be subdivided into surface runoff (SURO), interflow (IFWO), and active ground-water flow (AGWO). These components represent the volumes of water discharged to the stream from a pervious land segment (PERLND). Impervious land segments (IMPLNDs), by definition, have only a surface runoff (SURO) pathway. For the 4-year period of simulation of Red Clay Creek near Stanton, Del., the cumulative surface runoff is 19.4 in. and about 26 percent of total flow, interflow is 7.8 in. and about 10 percent of total flow, and active groundwater flow is 47.9 in. and about 64 percent of total runoff.

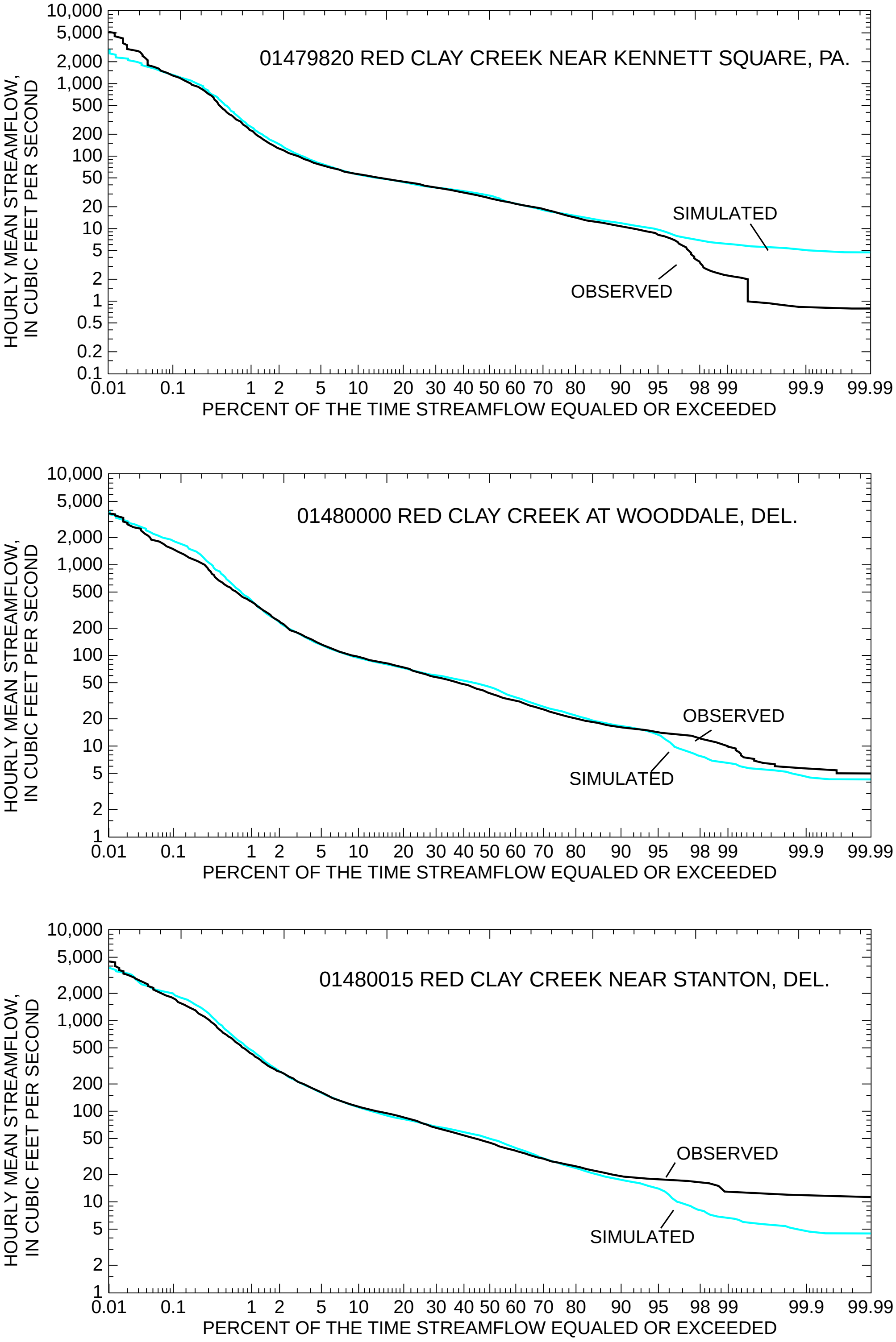

Figure 14. Duration curves of simulated and observed hourly mean streamflow for three sites on the main stem Red Clay Creek, Pennsylvania and Delaware, for the period October 1, 1994, through October 29, 1998.

Table 11. *Statistics for comparison of observed and simulated hourly and daily mean streamflow at the nonpoint-source water-quality monitoring site during the January - October 1998 nonpoint-source monitoring period and at three water-quality monitoring sites during the January 1994 - October 1998 calibration period in the Red Clay Creek Basin, Pennsylvania and Delaware*

Site	Type of mean values	Number of values	Streamflow, in cubic feet per second				Correlation coefficient	Model-fit efficiency
			Mean observed	Mean simulated	Mean error	Mean absolute error[1]		
Nonpoint-source monitoring period, January - October 1998								
Wooddale	Hourly	7,248	48.33	52.98	-4.647	13.29	0.80	0.64
Wooddale	Daily	302	48.33	52.98	-4.647	12.38	.85	.71
Calibration period, October 1994 - October 1998								
Kennett Square	Hourly	35,760	39.37	39.21	.153	11.52	.79	.40
Kennett Square	Daily	1,490	39.37	39.21	.153	10.27	.84	.50
Wooddale	Hourly	35,760	60.08	61.35	-1.29	15.92	.83	.69
Wooddale	Daily	1,490	60.08	61.35	-1.29	13.99	.89	.79
Stanton	Hourly	35,760	70.09	69.53	.557	18.17	.84	.68
Stanton	Daily	1,490	70.09	69.53	.557	15.66	.89	.79

[1] Mean absolute error = sum[|(simulated - observed)|/number of values].

Table 12. *Observed and simulated streamflow for Red Clay Creek near Stanton, Del., 1994-98*

Year	Streamflow, in inches			Percent difference[1]
	Simulated	Observed	Simulated - observed	
[2]1994	1.95	2.07	-0.12	-5.8
1995	12.4	11.7	.7	6.0
1996	32.2	33.1	-.9	-2.7
1997	16.7	17.6	-.9	-5.1
[3]1998	13.5	12.9	.5	4.7
Total (1994-98)	76.8	77.4	-.6	-.8

[1] 100 x (Simulated - Observed) / Observed.
[2] October 1 through December 31, 1994.
[3] Through October 29, 1998.

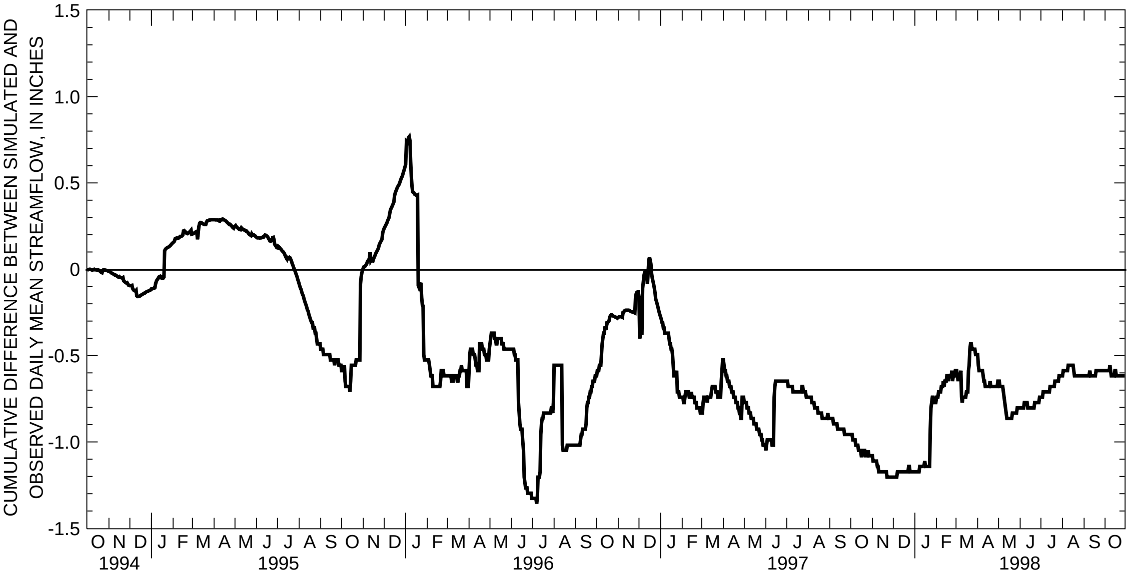

Figure 15. Cumulative difference between simulated and observed daily mean streamflow at streamflow-measurement station 01480015, Red Clay Creek near Stanton, Del., October 1, 1994, through October 29, 1998.

A well-calibrated HSPF model will simulate satisfactorily the proportioning of surface runoff, interflow, and ground-water components of the total volume of water leaving land areas and entering streams. Simulation of flow components is important because the contaminant transport in surface runoff, interflow, and ground water is affected by the amount and rate of water leaving the land through each process. As a check on the simulated proportion of base flow, fixed-interval and local-minimum base-flow-separation techniques (Sloto and Crouse, 1996; Pettyjohn and Henning, 1979) determined 65.8 and 64.3 percent, respectively, for base flow as percent of total flow for Red Clay Creek near Stanton. These percentages agree well with the HSPF simulated base-flow percentages, although values of active ground-water flow calculated in the HSPF simulation cannot be compared exactly to those calculated by fixed-interval or local-minimum base-flow-separation techniques because of differences in methodology. These base-flow-separation techniques do not compute interflow as a separate component. Rather, interflow (IFWO), as calculated in HSPF, is divided between base flow and surface runoff in unknown proportions.

The partitioning of PERLND water among SURO, IFWO, and AGWO affects the stream hydrograph and, consequently, the simulation of nonpoint-source constituent transport (Fontaine and Jacomino, 1997). The monthly contributions from SURO, IFWO, and AGWO for a wetter-than-average year (1996) and a drier-than-average year (1997) at Stanton, the most downstream calibration point that receives contributions from each of the three model segments, is presented in figure 16. Simulated surface runoff and interflow are greater in magnitude and represent a greater percent of simulated total runoff in the wet year, 1996, than in the dry year, 1997. In 1996 and 1997, SURO represented 9.8 and 2.9 in., respectively (31 and 18 percent, respectively), of the total runoff at Red Clay Creek near Stanton. Over the full simulation period at the three calibration sites, the average SURO ranged from 24 percent at Red Clay Creek near Wooddale to 26 percent at Red Clay Creek near Stanton.

Overall, the calibration of the hydrologic component of the HSPF model for the Red Clay Creek Basin generally is balanced over the full range of observed streamflows, even though more emphasis was placed on high-flow simulation. The model was calibrated at mainstem sites draining areas greater than 28 mi^2. As calibrated, the hydrologic component of the model nevertheless has limitations for the application of simulating water quality under stormflow conditions. These limitations, related primarily to the regionalization of

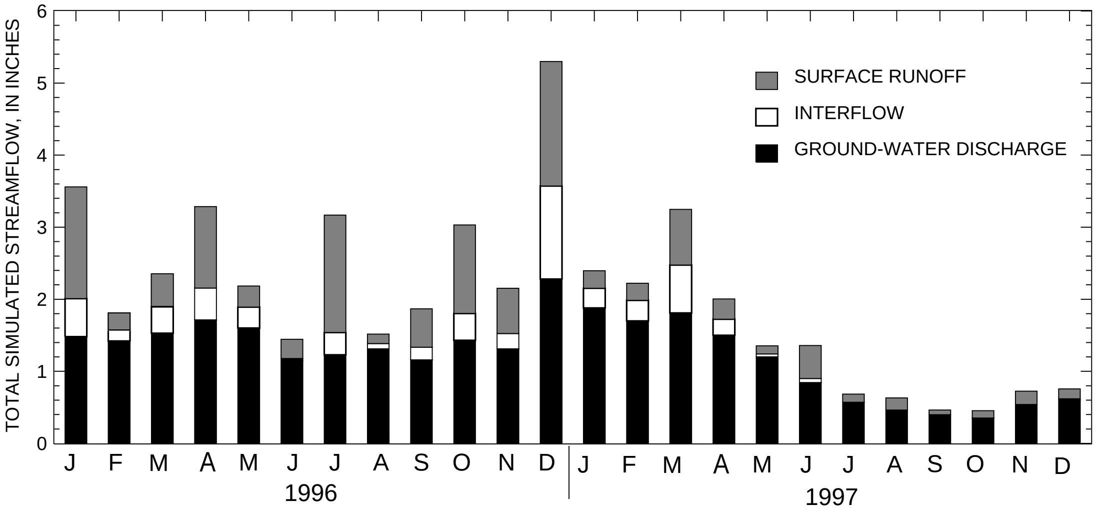

Figure 16. Simulated surface runoff, interflow, and base-flow monthly flow contributions from pervious land segments (PERLNDs) at the most downstream calibration site in the Red Clay Creek Basin, 01480015 Red Clay Creek near Stanton, Del., 1996-97.

distant point source precipitation data, result in a larger range and magnitude of errors for the simulated hydrologic responses to individual storm events than for simulated streamflow at daily or longer time steps. Because of the dependence of certain water-quality characteristics on streamflow conditions, limitations in the hydrologic simulations will affect water-quality simulations, particularly during stormflow conditions at sites draining relatively small areas. Errors in hourly stormflow simulation are due in part to errors in hourly rainfall estimated by disaggregating daily values. In the HSPF model for the adjacent Brandywine Creek Basin, errors commonly were found to be relatively greater at sites draining smaller areas (less than 10 mi^2) than at sites draining larger areas (more than 10 mi^2) (Senior and Koerkle, 2003a).

Sensitivity Analysis

A sensitivity analysis was performed to examine the influence of altering selected parameters on streamflow volume simulated by the Red Clay Creek HSPF model. For the analysis, parameters were altered one at a time. To a large extent, the relative sensitivities of the model results to changes in individual parameters are determined by the algorithm in which they are used. However, relative sensitivities also are affected by the calibrated values of other parameters because of various degrees of interdependence. IMPLND and RCHRES parameters were not included in the sensitivity analysis because they proved to have minimal effects on streamflow volumes during the calibration process. Rather, variations in the timing of stormflow discharges are affected most by varying IMPLND and RCHRES parameters.

Selected PERLND parameter values were multiplied by a factor prior to running a simulation while holding all other parameters constant. Typically, application of the multiplication factors resulted in doubling or halving the initial parameter value. In some instances, such as the lower zone evapotranspiration (LZETP) and ground-water recession (AGWRC) parameters, limitations on the range of allowable values prevented doubling or halving the values. In addition, the AGWRC parameter was only decreased because its calibrated value is close to the maximum allowable value. Sensitivity analyses were completed for the site that received flow originating from each of the three segments in the model structure, Red Clay Creek near Stanton, Del. The response of simulated runoff characteristics is listed in table 13.

Total runoff volumes at Stanton show the greatest sensitivity to lower-zone storage (LZSN), upper-zone evapotranspiration (UZSN), and lower-zone evapotranspiration (LZETP). The LZSN, UZSN, and LZETP parameters directly affected the amount of water available for simulated evapotranspiration (ET), although UZSN affects simulated ET to a lesser extent than LZSN and LZETP. ET is the largest component of the hydrologic budget. For the adjacent Brandywine

Table 13. *Sensitivity analysis of modeled runoff characteristics at Red Clay Creek near Stanton, Del. (01480015), to variations in selected pervious land (PERLND) parameters*

[ET, evapotranspiration; Model parameters: AGWRC, active ground-water recession rate; INFILT, infiltration; LZSN, lower-zone storage; CEPSC, interception storage; UZSN, upper-zone storage; SLSUR, slope of overland flow; NSUR, Manning's n for overland flow; INTFW, interflow; IRC, interflow recession rate; LZETP, lower-zone evapotranspiration]

Parameter	Multiplier	Runoff errors (in percent)						Total inches (Cumulative for 1994-98)			
		Total runoff volume	50-percent low flow	10-percent high flow	Seasonal runoff volume	Summer storm volume	Average storm peak	Total runoff	Surface runoff	Interflow	Total ET
Calibrated value[1]	1	-0.8	-3.8	2.3	3.4	-9.9	-6.2	76.77	19.36	7.78	101
AGWRC	.75	2.4	-61	37.1	49.5	-20.3	.5	79.24	19.28	7.72	99.92
INFILT	2	.5	13.5	-20.3	12.7	0	-46.9	77.78	12.62	4.84	99.65
INFILT	.5	-1.4	-24.6	31.3	21.6	-22.5	46.9	76.3	29.95	8.69	102.1
LZSN	2	-12.7	-18.7	-14.5	8.5	6.3	-28.8	67.52	16.47	5.14	102.3
LZSN	.5	8.7	-1.4	22.1	29	-38.8	18.6	84.1	22.91	11.81	96.34
CEPSC	2	-2.9	-9.9	3.1	9.6	-11.8	-4	75.11	19.57	8.09	102.8
CEPSC	.5	.6	.3	1.6	.4	-8.9	-8.5	77.85	19.15	7.58	99.79
UZSN	2	-4.2	-2.1	-9.7	1.9	-5.9	-26.6	74.09	16.4	6.57	103
UZSN	.5	2.2	-6.1	13.9	.9	-9.9	13	79.08	22.5	8.97	99.11
SLSUR	2	-.7	-4.3	3.6	3.4	-10.2	-2.8	76.82	20	7.53	100.9
SLSUR	.5	-.8	-3.2	.9	3.3	-9.7	-9.6	76.71	18.63	8.09	101
NSUR	2	-.9	-2.6	-.6	3.1	-8.9	-14.1	76.66	17.86	8.41	101
NSUR	.5	-.6	-4.9	4.8	3.7	-10.3	-0.6	76.87	20.67	7.27	100.9
INTFW	2	-.5	-4.3	.6	4.9	-12.1	-33.3	76.96	13.95	14.75	100.8
INTFW	.5	-1	-2.9	5.9	.3	-9	17.5	76.57	25.24	0.1	101.1
IRC[2,3]	2	-.8	.3	-5.4	1.5	-6.1	-9.6	76.73	19.36	7.75	101
IRC[2]	.5	-.8	-4.4	5.3	3.4	-9.8	-2.8	76.77	19.36	7.78	101
LZETP[2,3]	1.25	-3.5	-7.7	-.6	2.2	-8.7	-9.6	74.68	18.83	7.37	103.9
LZETP[2]	.75	2.4	.7	5.9	4.9	-11.7	-1.7	79.21	20.01	8.32	97.6

[1] All parameters.

[2] Included monthly entries.

[3] For IRC and LZETP, when increasing values in UCI file reached or exceeded 1, the value was input as 0.99 or 0.9.

Creek Basin, ET is estimated to account for about 55 percent of the hydrologic budget (Sloto, 1994). Interception storage (CEPSC) and the active ground-water recession constant (AGWRC) also affect total runoff but more moderately.

The 10-percent highest flows are sensitive primarily to the infiltration rate (INFILT) and sensitive secondarily to LZSN and AGWRC. The 50-percent lowest flows are sensitive primarily to AGWRC and sensitive secondarily to INFILT.

Seasonal runoff volumes are most sensitive to the active ground-water recession parameter (AGWRC). Seasonal runoff volume refers to the differences between summer (June, July, and August) runoff volumes and winter (December, January, and February) runoff volumes. Secondary sensitivity is greatest for LZSN. AGWRC determines how rapidly base flow diminishes over time after recharge to ground-water storage. Ground-water storage is controlled, in part, by infiltration and water loss to lower-zone storage and evapotranspiration. Recharge to ground-water storage typically exhibits seasonality. Base flow simulated with high ground-water recession rates (AGWRC close to 1.0) shows or even amplifies the seasonality in ground-water storage, whereas, base flow simulated with low ground-water recession rates (AGWRC less than 0.95) suppresses seasonal fluctuations in ground-water storage.

Summer storm volumes show primary sensitivity to LZSN and secondary sensitivity to INFILT. LZSN generally is not considered as having much effect over storm volumes. However, because HSPEXP calculates storm volumes over only whole 24-hour increments, storm volumes for short-duration events, which are more prevalent in the summer, will include more base flow. These base-flow periods are affected by the LZSN parameter. In addition, HSPEXP analysis is limited to 36 storms. Eleven of the 36 storms selected for analysis were from the drier than average 1997-98 period that coincided with available water-quality data. Storms from this period tend to be smaller (lower rainfall amounts than storms during other periods) with the result that HSPEXP calculated storm volumes that contain a large proportion of base flow.

Peak stormflows are most sensitive to INFILT. Infiltration rate affects stormflow through diversion of potential surface runoff into the soil storages. Surface runoff controls peak stormflows. Peak stormflow was next most sensitive to interflow (INTFW), LZSN, and UZSN. INTFW diverts surface runoff into interflow storage. Lower zone storage (LZSN) and upper zone storage (UZSN) have a slightly smaller but similar effect on peak stormflows. In addition to these PERLND parameters, peak stormflow also is affected by IMPLND parameters, if sufficient IMPLND area is present, and by RCHRES storages as defined in the F-Tables. As with storm volumes, the choice of storms selected for inclusion into HSPEXP has a substantial effect on the reported peak-stormflow statistics.

Model Limitations

The final calibration of the hydrology component of the HSPF model for Red Clay Creek satisfies most of the recommended calibration criteria, but has limitations. These limitations can be classified as either errors in the input and calibration data or errors in the model structure. Errors in the input data may result from the measurement, interpolation, and extrapolation of precipitation and other climatic data, and discharge and withdrawal rates. Errors in calibration data include those involved in the measurement of observed streamflow data. Measurement errors result from equipment malfunction, incorrect data transcription, and other problems, including ice. Specific information required to evaluate random or transitory measurement errors generally is unavailable. Interpolation errors can occur when data are disaggregated to smaller time steps. Extrapolation errors can occur when spatial variations and timing in data are lost by applying localized data to large areas.

Errors resulting from extrapolation, interpolation, and disaggregation of the precipitation data probably are the greatest limitation to achieving the best possible model calibration and simulations. Applying point location data from four raingages to the entire 54-mi^2 basin and disaggregating daily precipitation data to hourly data values introduces substantial errors; stormflow simulations, in particular, have errors in peak flows and total volumes regularly exceeding 100 percent. These errors will translate into the water-quality calibration of the model. In addition, temporal errors in stormflow simulations can be detrimental to the water-quality calibration even if stormflow peaks and volumes are well simulated. The overall effect of these errors is an increase in the average error as the time period of simulation is decreased. Other climatic data such as air temperature, solar radiation and wind speed are subject to the same type of errors but are less important factors than precipitation in the streamflow simulation.

Measurement errors in observed streamflow are known and corrected in some instances but unknown and roughly estimated in other instances such as ice-affected streamflow data. In many cases, corrections are limited to daily values and hourly data are left uncorrected or missing. Periods of missing hourly streamflow record were filled with estimated data for the model to calculate statistics. However, the errors associated with this estimated data are unknown. The USGS (Durlin and Schaffstall, 1999) rates periods of estimated record as poor and states that errors greater than 15 percent can be expected in some instances. Errors in observed streamflow data can be expected to affect the statistics used for calibration evaluation and, if severe, lead to incorrect selection of parameter values.

Errors in the model structure mainly are due to limited resolution of PERLND, IMPLND, and RCHRES spatial characteristics and incorrectly specified model parameters. In general, spatial errors result from the loss of local variation in spatial characteristics. Lack of data resolution and the need to limit the complexity of the model structure are the primary reasons for this loss. For example, in the Red Clay Creek model, the number of pervious land-use categories has been limited to 10. In actuality, more than 10 distinct land-use categories are present. Further, each of these PERLND categories is assigned individual calibration parameters that are selected to represent a composite average for that category. Because of this spatial averaging, model simulation is limited in the capacity to resolve responses from land uses with limited areal extent or that differ greatly from the average.

Many HSPF parameters are not expressed in terms of known physical characteristics, making selection of parameter values ambiguous and may lead to incorrect specification in model simulation. For example, the parameter AGWRC is not defined in terms of established ground-water hydrologic characteristics. Also, in the case of the parameter INFILT, published soil permeability values cannot be used directly but only as a guide. A satisfactorily calibrated model can be produced with more than one combination of parameters and therefore is not unique.

SIMULATION OF WATER QUALITY

Suspended sediment and nutrients were simulated for the Red Clay Creek Basin. The simulation included delivery of suspended sediment and nutrients from pervious and impervious land areas to stream reaches and transport and chemical reactions in the stream reaches. The instream simulation of nutrients requires information about stream temperature and dissolved oxygen, both of which were simulated in the model. Stream temperature is an important factor in determining water quality because temperature affects saturation levels of dissolved oxygen and rates of chemical reactions. Dissolved oxygen concentrations affect the extent of chemical reactions involving nutrients, such as nitrification. In HSPF, the simulation of water quality is based on and is an extension of the hydrologic simulation.

The simulation of water quality was undertaken with the following assumptions: (1) land-based contributions of sediment and nutrients could be simulated by a simplified set of land-use categories; (2) water quality could be represented by the condition where chemical transformation of nutrients are simulated explicitly in the stream channel but not in land processes; (3) the contribution of sediment from bank erosion in the stream channel can be estimated by sediment from pervious land areas.

Calibration

Each land-use category is assigned parameters that affect interflow and ground-water temperature, sediment release, and nutrient contributions from land areas. Stream reaches are assigned parameters that affect the simulation of stream temperature, sediment transport, bed erosion and deposition, and chemical reactions in the stream channel. Individual parameters were adjusted until the simulated water quality was an acceptable match to observed water quality. The computer program GenScn (Kittle and others, 1998), a graphical interface to HSPF, was used for the water-quality calibration.

Suggested guidelines to evaluate sediment and water-quality calibration, including the nutrients nitrogen and phosphorus, in the HSPF model are given in percentage differences between observed and simulated monthly or annual values (table 14) (Donigian and others, 1984). Comparison of loads, rather than instantaneous concentrations, are considered more appropriate when evaluating

Table 14. *Suggested criteria to evaluate water-quality calibration for an Hydrological Simulation Program–Fortran (HSPF) model (from Donigian and others, 1984)*

[<, less than]

Constituent	Difference between observed and simulated monthly or annual values, in percent		
	Quality of calibration		
	Very Good	Good	Fair
Sediment	<15	15-25	25-35
Water quality (includes nitrogen and phosphorus)	<20	20-30	30-40

water-quality simulations of nonpoint-source constituents (Donigian and others, 1984). Comparison of instantaneous concentrations may result in larger apparent differences between observed and simulated values than comparison of loads for some time periods, such as hours or days, because of the effect of even small lags (errors) in the timing of storm events. In addition, simulation errors usually are larger for water-quality concentrations than for streamflow because of the greater complexity in simulating water quality than streamflow.

Water-quality calibration included stormflow and base-flow conditions. Because the hydrologic part of the model is integral to simulation of water quality, only well-simulated storms ideally would be used for calibration of suspended sediment and nutrients. In all cases, however, the simulated storm hydrograph does not replicate the observed storm hydrograph well, especially with respect to peak flows. Therefore, simulated concentrations of suspended sediment, nitrate, ammonia, and phosphorus cannot be expected to exactly replicate observed concentrations for all storms. Based on limited data and model guidelines (Donigian and others, 1984), calibration was considered satisfactory when the general pattern of simulated streamflow and suspended-sediment and nutrients concentrations was simulated and when, for better simulated storms, simulated loads of suspended sediment and nutrients were within an order of magnitude of observed loads. Individual storm errors considerably larger than the recommended criteria of 40 percent or less for monthly or annual values for fair to good water-quality calibration may occur and have little effect on the overall calibration (Donigian and others, 1984). Calibrated values for water-quality parameters are given in the UCI file for Red Clay Creek (appendix 2).

Monthly and annual load data were not available to assess calibration errors. Simulated and observed load data for four to five storms in 1998 were used to provide estimates of calibration accuracy. Loads were calculated from measured discharge and constituent concentrations in flow-weighted composite samples collected during storms. However, these limited data do not provide a long-term measure of model accuracy and may include one or more poorly simulated storms or questionable laboratory analyses, which can have a large effect on the apparent model accuracy. The calibration error, calculated as [(simulated-observed) / observed] for the total flow volume or constituent load for the five storms sampled, is listed in table 15. Calibration errors for individual storms at the nonpoint-source monitoring site are listed and discussed in more detail in subsequent sections describing calibration of suspended sediment, nitrogen, and phosphorus. Generally for these storm events, loads of suspended sediment, nitrogen, and phosphorus were undersimulated when streamflow was undersimulated and oversimulated when streamflow was oversimulated. Dissolved constituents were simulated better than particulate constituents.

Table 15. *Cumulative calibration errors in flow volume and constituent loads for selected storms in 1998 at 01480000 Red Clay Creek at Wooddale, Del., the nonpoint-source monitoring site in the Red Clay Creek Basin*

Site	Number of storms	Cumulative calibration error for selected storm simulations in 1998, in percent[1]						
		Streamflow volume	Suspended sediment load	Nitrate load	Dissolved ammonia load	Particulate ammonia load	Dissolved ortho-phosphate load	Particulate phosphorus load[2]
Red Clay Creek at Wooddale, Del.	5	-24	-44	-41	18	-58	-32	-35

[1] Percent calibration error = 100 x (simulated-observed)/observed.

[2] One fewer storm was available for comparison because total phosphorus was not analyzed in the October 1998 storm.

Water Temperature

Simulated stream water temperature was calibrated against observed data collected at three streamflow-measurement stations on the Red Clay Creek where intermittent water-temperature data were available. Comparison of simulated and observed daily mean water temperature at the three streamflow-measurement stations (fig. 17) shows a fairly good correlation between simulated and observed water temperature over the observed range of 0 to 25°C except for water temperatures below about 10°C at the Kennett Square streamflow-measurement station. The line of identity shown in figure 17 indicates where the simulated values exactly equal the observed values. Simulated water temperatures below about 10°C at the Kennett Square streamflow-measurement station are greater than observed water temperatures. The assumption of a constant 12°C discharge temperature at the Kennett Square wastewater-treatment plant may, in part, account for these higher simulated water temperatures. Errors in the simulated water temperatures, excluding any overall bias, fall within plus or minus 4°C. Because water temperature affects the rate of chemical reactions and biological processes involving nutrients in the stream, errors in the temperature simulation will affect calibration of the nutrient simulation.

Sediment

Calibration of suspended sediment in the stream channel largely is done by adjusting parameters affecting soil detachment, soil washoff, and soil scour processes for pervious land surfaces, solids build up and washoff processes for impervious land surfaces, and sediment transport in the channel, including deposition on and scour of the channel bottom controlled by setting shear stress regimes. Sediment in streams may be derived from land areas, streambanks, and beds. For the calibration, no net erosion of streambeds was assumed over the simulation period and, therefore, the principal sources of sediment were assumed to be land areas and streambanks. Because the process of bank erosion is not included in the HSPF model simulation, sediment from streambanks was estimated by simulating scour in pervious land areas. Simulated concentrations of suspended sediment were evaluated against total suspended solids data collected by USGS in 1998 at 01480000 Red Clay Creek at Wooddale, the nonpoint-source monitor-

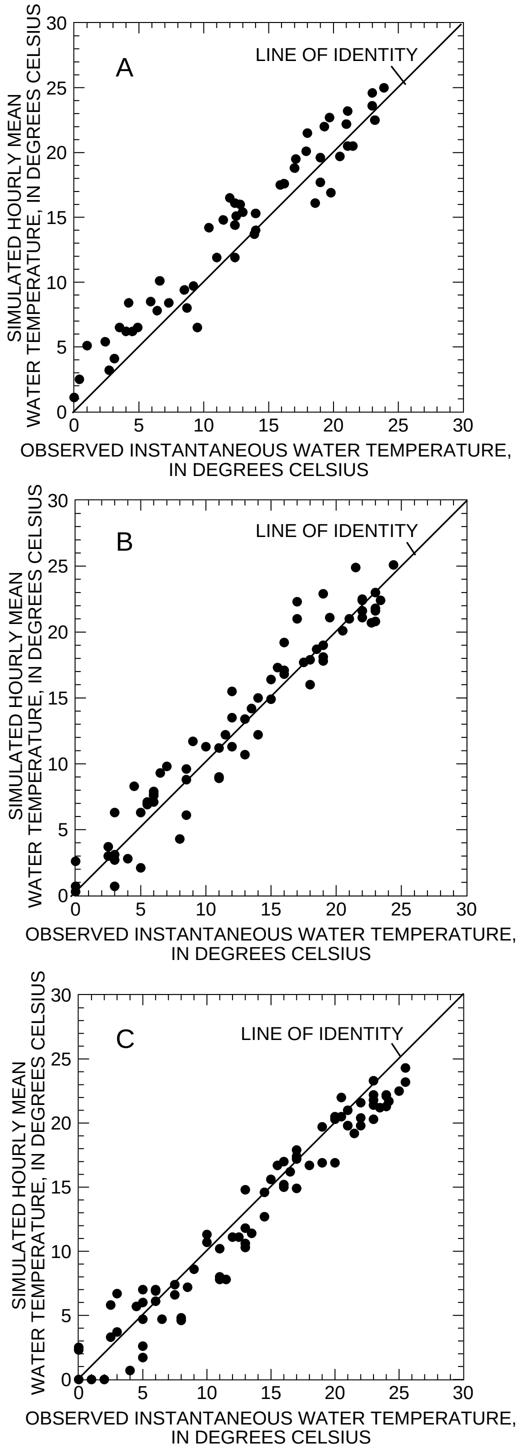

Figure 17. Simulated hourly mean and observed instantaneous water temperature at streamflow-measurement stations (A) 01479820, Red Clay Creek near Kennett Square, Pa., (B) 01480000, Red Clay Creek at Wooddale, Del., and (C) 01480015, Red Clay Creek at Stanton, Del., October 1994 - October 1998.

ing site, as well as data collected by PADEP at sites in Pennsylvania (1995-98) and by DNREC at sites in Delaware (1994-98).

The results of suspended-sediment simulation at Red Clay Creek at Wooddale provides a measure of the overall model accuracy on a basin-wide scale. Instantaneous concentrations of suspended solids were measured for five storms and four base-flow events in 1998. Reported concentrations of suspended solids (nonfilterable material) were considered estimates for suspended-sediment concentrations. Suspended-solids concentrations are not always accurate estimates of suspended-sediment concentrations and tend to be biased low, especially for conditions when sand-sized particles represent more than 25 percent of suspended sediment (Gray and others, 2000). When suspended solids are used as a surrogate for suspended-sediment concentrations, the resulting errors in load computations can be as large as 4-5 orders of magnitude (U.S. Geological Survey, 2000). As noted earlier, only well-simulated storms (simulation error less than 20 percent for storm peaks, for example) would, ideally, be used for calibration of suspended sediment. In many cases, storms were not well simulated. Observed and simulated streamflow and suspended sediment for the five sampled storms at Red Clay Creek at Wooddale are shown in figure 18. Streamflow is undersimulated for all five storms. For the three storms during which discrete samples were collected, the simulated suspended-sediment concentrations range from less than, similar to, and greater than observed concentrations of suspended solids.

Composite samples collected during storms at the Wooddale monitoring site in the Red Clay Creek Basin in 1998 allow comparison of simulated and observed loads for the periods monitored. Peak flows were greatest in the March and June storms and least in the May and October storms (table 16). For the sampled storm periods, streamflow volume and suspended-sediment loads tend to be undersimulated. The difference between observed and simulated streamflow ranged from -2 to -59 percent for individual storms and was -24 percent for the total of all storms. The difference between observed and simulated suspended-sediment loads ranged from -91 to greater than (>) 1,903 percent for individual storms and was -44 percent for the total of all storms. The May storm had the largest percentage difference between observed and simulated suspended-sediment load yet was the smallest in magnitude of the sampled storms. The less than 1 mg/L concentration of suspended solids reported in the composite sample for that storm is uncharacteristically low even for low-magnitude stormflow conditions and likely in error.

Comparison of simulated and observed values (table 16) for all sites indicate that when flow is undersimulated or over simulated, loads of suspended sediment tend to be undersimulated or oversimulated, respectively, to a greater degree. For example, in a case of undersimulation, the cumulative error was -24 percent for simulated streamflow and -44 percent for simulated suspended-sediment load at Wooddale.

Table 16. *Simulated and observed streamflow and loads of suspended sediment for storms sampled in 1998 at 01480000 Red Clay Creek at Wooddale, Del.*

[ft^3/s, cubic feet per second; >, greater than; mg/L, milligram per liter]

Dates of storm sampling	Peak discharge[1] (ft^3/s)	Streamflow volume (millions of cubic feet)			Suspended-sediment load (tons)		
		Simulated	Observed	Percentage difference[2]	Simulated	Observed	Percentage difference[2]
Red Clay Creek at Wooddale, Del.							
March 8-9	688	14.68	19.33	-24	79.37	76.33	4
May 2-3	66	7.45	7.62	-2	4.82	[3].24	>1,903
June 12	580	3.05	7.38	-59	6.36	73.92	-91
July 8-9	280	7.77	9.11	-15	6.29	23.60	-73
October 8-9	74	4.20	5.68	-26	3.60	5.20	-31
Total (all storms)		37.15	49.11	-24	100.4	179.3	-44

[1] Peak mean hourly discharge during period of composite sampling.

[2] 100 x (simulated-observed)/observed.

[3] Reported value of 1 mg/L for total suspended solids concentration in composite sample appears erroneously low.

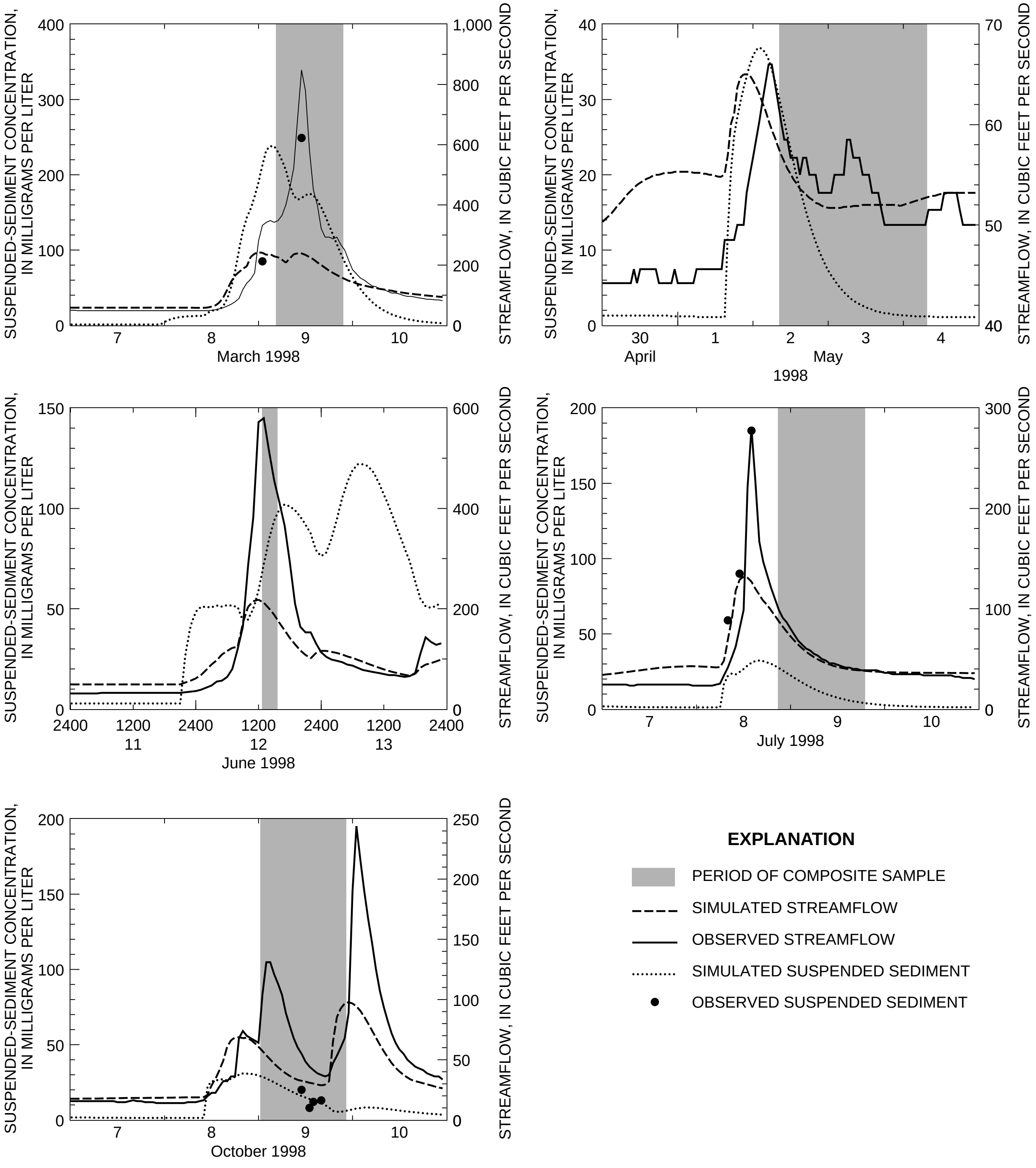

Figure 18. Simulated and observed streamflow and suspended-sediment concentrations and period of composite sample during five storms in 1998 at streamflow-measurement station 01480000, Red Clay Creek at Wooddale, Del.

The error in the water-quality component of the load simulation can be estimated by adjusting for the error in streamflow simulation as follows, although this approach does not account for a non-linear relation between flow and concentration:

$$\text{percentage error in water-quality component of load} = 100 \times ([(L_s/L_o) / (Q_s/Q_o)] - 1), \qquad (1)$$

where

L_s is simulated load,
L_o is observed load,
Q_s is simulated streamflow, and
Q_o is observed streamflow.

Using this approach, the error in the suspended-sediment component of the cumulative load is -26 percent at Red Clay at Wooddale. The non-linear relation between streamflow and sediment accounts for some of the differences in errors for streamflow and suspended-sediment simulations. Suspended-sediment simulation is dependent on accuracy of precipitation data and the flow simulation and has a large degree of error.

Simulated concentrations of suspended sediment under base-flow conditions generally were within one order of magnitude of observed concentrations at the Wooddale monitoring site (fig. 19). For these base-flow samples, streamflow was well simulated, as shown in figure 19. The average percentage difference between simulated and observed base flow was -15 percent, indicating moderate oversimulation (exceedance of observed values).

Instantaneous loads, calculated from measured streamflows and suspended-solids concentrations in grab samples collected monthly or bimonthly by PADEP and DNREC at three streamflow-measurement stations, also were used to evaluate model calibration. At the streamflow-measurement stations, 01479820 Red Clay Creek near Kennett Square, Pa., 01480000 Red Clay Creek at Wooddale, Del., and 01480015 Red Clay Creek near Stanton, Del., instantaneous streamflows were moderately well simulated (fig. 20), with differences between simulated and observed ranging from -78 to 43 percent. At the three sites, most simulated suspended-sediment instantaneous loads were within an order of magnitude (or factor of 10) of observed loads, and in general are only moderately well simulated (fig. 21). Most of the grab samples were collected from July 1995 through October 1998 under moderate (20 to 100 ft^3/s at Stanton, for example) to low-flow (<20 ft^3/s at Stanton) conditions, although a few samples were collected under relatively high-flow (>200 ft^3/s at Stanton) (fig. 20) conditions. The median percent differences between simulated suspended-sediment loads and observed suspended-solids loads at the stations 01479820, 01480000, and 01480015 were 33, -16, and -16 percent, respectively. Although data on monthly and annual loads of suspended sediment

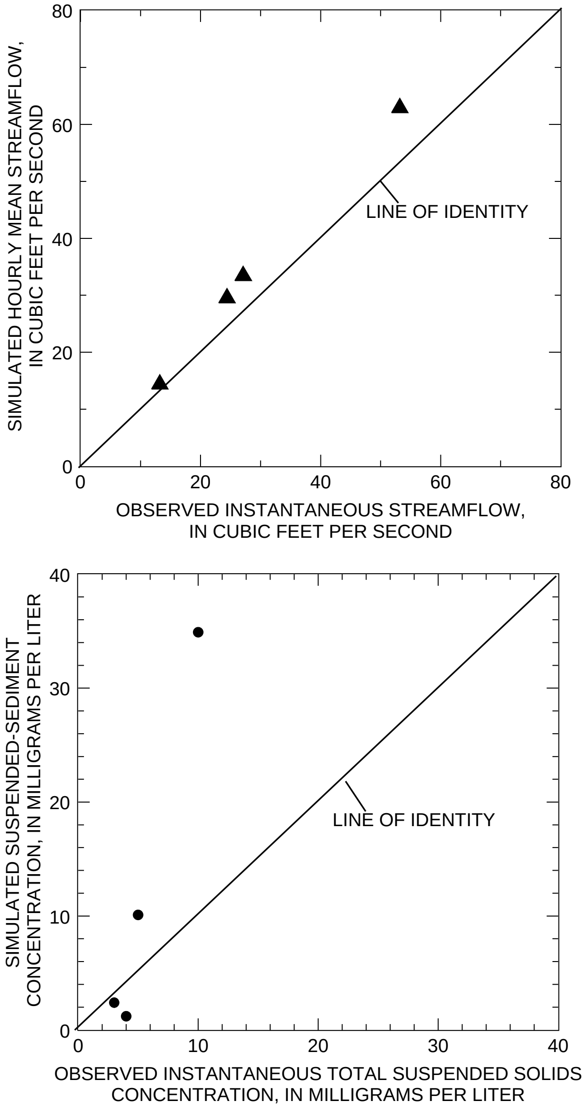

Figure 19. Simulated hourly mean streamflow and suspended-sediment concentrations, and observed instantaneous streamflow and total suspended-solids concentrations under base-flow conditions at monitoring site, 01480000, Red Clay Creek at Wooddale, Del.,1998.

are not available, the median of instantaneous loads at the three stations provides an estimate of the adequacy of the sediment calibration as “fair” to “good” on the basis of guidelines described by Donigian and others (1984).

In summary, the quality of the suspended-sediment calibration ranges from less than “fair” (more than 35-percent error) to “very good” (less than 15-percent error) for individual storms based on criteria from Donigian and others (1984). Simulated instantaneous suspended-sediment loads at three long-term fixed time-interval sites generally were within one order of magnitude of observed loads. These results indicate the range of variability that might be expected in simulating individual storms or instantaneous values. Comparison of the observed and simulated suspended-sediment concentration duration curves indicates that over relatively long time periods (5 years or more), the model results statistically are similar to observed data (Senior and Koerkle, 2003a).

Simulated yields of sediment differ by land use and vary with precipitation from year to year (table 17). Simulated yields of sediment by land use were similar in the three segments (tables 17 and 18) and are within the ranges reported for equivalent land-use types by Dunne and Leopold (1978, p. 520-522). Most of the simulated sediment yield was from land areas. Using pervious-land scour as an estimate of bank erosion, the average simulated amount of sediment removed by scour for the years 1994-97 differed among land uses and ranged from 0 to 17 percent of the total sediment yield. The highest percentage of sediment yield produced by scour was in urban and sewered residential land uses (median values of 8 and 4 percent, respectively) and the lowest was in forested and wetland land uses (median values of 1 and 0 percent, respectively). In areas of agricultural land use, the range of average simulated scour (bank erosion) was about from 1 to 3 percent of total sediment yield for 1994-97 and appears to be slightly lower or similar to estimates obtained elsewhere with similar physical settings. In a study of sediment sources in two agricultural basins in the United Kingdom, bank erosion was estimated to contribute about 10 percent or less of the sediment yield (Russell and others, 2001).

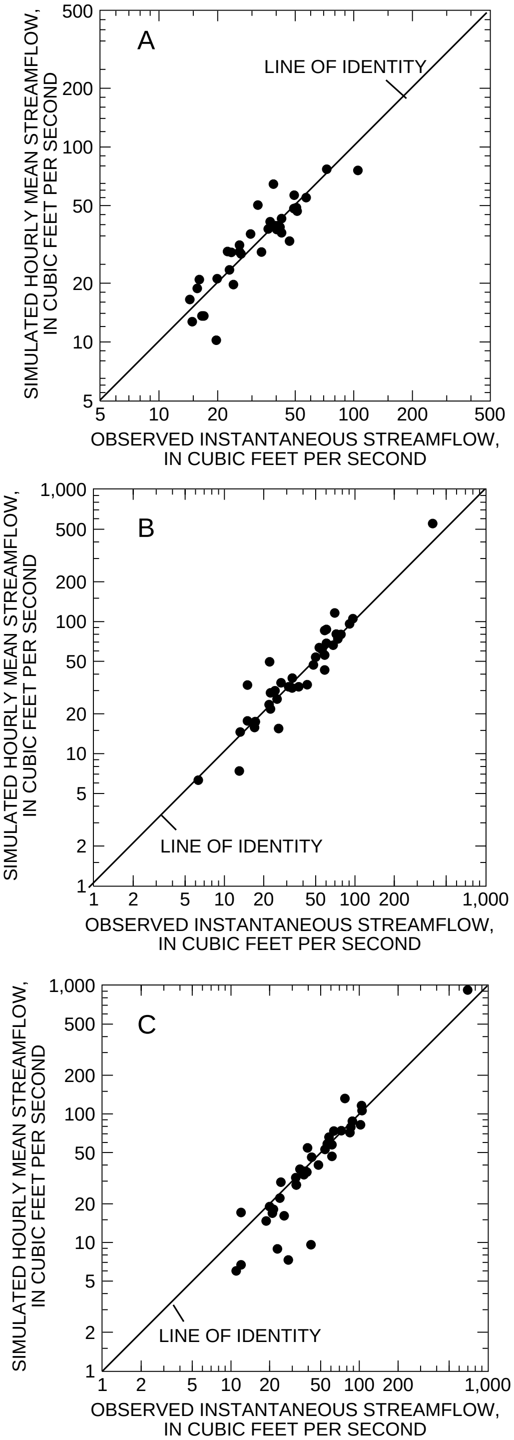

Figure 20. Simulated hourly mean and observed instantaneous streamflow at streamflow-measurement stations (A) 01479820, Red Clay Creek near Kennett Square, Pa., (B) 01480000, Red Clay Creek at Wooddale, Del., and (C) 01480015, Red Clay Creek at Stanton, Del., October 1994 - October 1998.

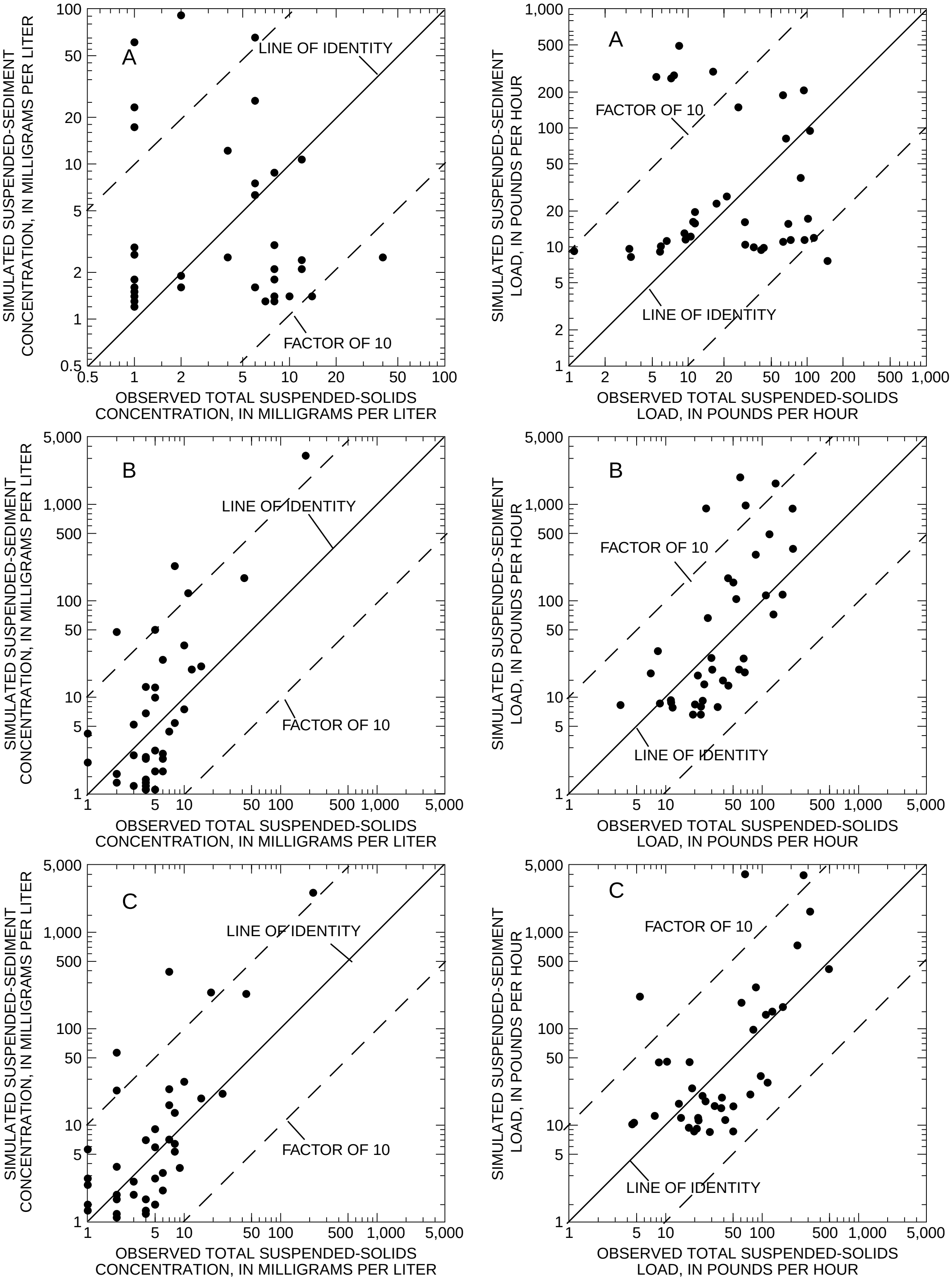

Figure 21. Simulated hourly mean suspended-sediment and observed instantaneous total suspended-solids concentrations and hourly mean loads at streamflow-measurement stations (A) 01479820, Red Clay Creek near Kennett Square, Pa., (B) 01480000, Red Clay Creek at Wooddale, Del., and (C) 01480015, Red Clay Creek at Stanton, Del., October 1994 - October 1998.

Table 17. *Observed annual precipitation and simulated annual sediment yields by land use for three segments of Hydrological Simulation Program–Fortran (HSPF) model for Red Clay Creek Basin, Pennsylvania and Delaware, 1995-97*

	Segment	Year			
		1995	1996	1997	1995-97 average
Precipitation (inches)	7,4,6	40.59	61.98	35.01	45.86
Simulated sediment yield (tons per acre per year) by land-use category[1]					
Residential - unsewered	7	.150	.649	.083	.294
Residential -sewered	7	.215	.681	.111	.336
Urban	7	.412	.712	.174	.433
Agricultural - animal/crop	7	1.80	3.32	1.24	2.12
Agricultural - row crop	7	1.76	3.30	1.18	2.08
Agricultural - mushroom	7	2.04	4.08	.945	2.36
Forested	7	.015	.226	.019	.087
Open	7	.183	.650	.116	.316
Wetlands/water	7	.002	.021	.002	.009
Undesignated	7	.175	.650	.115	.313
Impervious - residential	7	.206	.188	.203	.199
Impervious - urban	7	.814	.745	.801	.787
Simulated sediment yield (tons per acre per year) by land-use category[1]					
Residential - unsewered	4	.131	.575	.065	.257
Residential -sewered	4	.176	.622	.081	.293
Urban	4	.363	.655	.143	.387
Agricultural - animal/crop	4	1.46	3.28	.958	1.90
Agricultural - row crop	4	1.41	3.25	.873	1.84
Agricultural - mushroom	4	1.89	3.97	.849	2.24
Forested	4	.011	.157	.012	.060
Open	4	.126	.581	.073	.260
Wetlands/water	4	.002	.020	.002	.008
Undesignated	4	.120	.564	.066	.250
Impervious - residential	4	.205	.187	.202	.198
Impervious - urban	4	.812	.742	.798	.784
Simulated sediment yield (tons per acre per year) by land-use category[1]					
Residential - unsewered	6	.070	.323	.040	.144
Residential -sewered	6	.113	.519	.065	.232
Urban	6	.224	.608	.133	.322
Agricultural - animal/crop	6	.997	3.020	.820	1.61
Agricultural - row crop	6	.953	2.950	.762	1.56
Agricultural - mushroom	6	.981	3.640	.456	1.69
Forested	6	.007	.082	.012	.033
Open	6	.111	.453	.074	.213
Wetlands/water	6	.001	.009	.001	.004
Undesignated	6	.110	.450	.073	.211
Impervious - residential	6	.204	.187	.202	.198
Impervious - urban	6	.808	.742	.798	.783

[1] In pervious areas, unless noted.

Table 18. *Observed annual precipitation and simulated average annual sediment yield by land use for pervious and impervious land areas in three segments of Hydrological Simulation Program–Fortran (HSPF) model for Red Clay Creek Basin, Pennsylvania and Delaware, 1995-97*

	1995-97 Average			
	Segment 7	Segment 4	Segment 6	Average of all segments
Precipitation (inches)	[1]45.86	45.86	45.86	45.86
Simulated average annual sediment yield (tons per acre per year) by land-use category[2]				
Residential - unsewered	.294	.257	.144	.232
Residential -sewered	.336	.293	.232	.287
Urban	.433	.387	.322	.381
Agricultural - animals / crops	2.12	1.90	1.61	1.88
Agricultural - row crop	2.08	1.84	1.56	1.83
Agricultural - mushroom	2.36	2.24	1.69	2.10
Forested	.087	.060	.033	.060
Open	.316	.260	.213	.263
Wetlands / water	.009	.008	.004	.007
Undesignated	.313	.250	.211	.258
Impervious - residential	.199	.198	.198	.198
Impervious - urban	.787	.784	.783	.785

[1] Precipitation for segment 7 = 0.85 × precipitation at Coatesville 2 W.

[2] In pervious areas, unless noted.

Dissolved Oxygen and Biochemical Oxygen Demand

Dissolved oxygen and biochemical oxygen demand (BOD) must be simulated in order to simulate nutrients in the stream. The simulation of dissolved oxygen included the instream effects of air and water temperature, reaeration, advection, and algal activity (photosynthesis and respiration). Oxygen concentrations were simulated in land-surface runoff and were fixed in interflow and ground water. Dissolved-oxygen concentration data collected intermittently at three streamflow-measurement stations in the Red Clay Creek Basin were used to evaluate the dissolved-oxygen simulation. In order to reproduce the temporal pattern of diurnal fluctuations in dissolved-oxygen concentrations observed at three continuous monitoring sites on the Brandywine Creek, simulation of plankton was needed (Senior and Koerkle, 2003a), and therefore, simulation of phytoplankton and periphyton was included in the water-quality modeling for Red Clay Creek. The simulation of BOD from nonpoint sources included transport of BOD from land to streams and instream processes of BOD decay, settling, and advection. Concentrations of BOD in the soil (sediment), interflow, and ground water were fixed in amounts that differed by land use. Estimates of BOD in soil, interflow, and ground water were derived from an HSPF model of the Pautuxent River Basin in northeastern Maryland (Stephen D. Preston, U.S. Geological Survey, written commun., 1995). BOD concentration data from the analysis of grab and composite stream samples collected at the nonpoint-source monitoring site were used to evaluate the BOD simulation.

The general pattern of seasonal changes in dissolved-oxygen concentrations were simulated by the model with varying degrees of accuracy, as shown in figure 22 for three sites on Red Clay Creek. Simulated dissolved-oxygen concentrations tended to be lower than observed concentrations in the winter months for Red Clay Creek near Kennett Square, Pa., and higher than observed concentrations throughout the year at the other two sites downstream (fig. 22). The diurnal fluctuation in dissolved-oxygen concentrations attributed to processes of algal photosynthesis and respiration becomes more pronounced in the summer months than at other times of the year.

At Red Clay Creek near Kennett Square, the difference between simulated hourly mean and observed instantaneous dissolved-oxygen concentrations ranged from -30 to 19 percent [100 × (simulated - observed) / observed] and the average difference was -3 percent for 35 observations made from July 1995 through October 1998. At Red Clay Creek at Wooddale, the difference between simulated hourly mean and observed instantaneous dissolved-oxygen concentrations ranged from 3 to 77 percent and the average difference was 31 percent for 36 observations made from October 1994 through October 1998. At Red Clay Creek near Stanton, the difference between simulated hourly mean and observed instantaneous dissolved-oxygen concentrations ranged from 0 to 135 percent and the average difference was 33 percent for 39 observations made from October 1994 through October 1998. These results indicate that dissolved-oxygen concentration tends to be slightly undersimulated at the Kennett Square site and moderately (by about 20 percent) oversimulated at the Wooddale and Stanton sites downstream (fig. 23).

The simulation of phytoplankton was evaluated using chlorophyll-*a* concentration data collected under base-flow conditions in 1998 as part of the nonpoint-source monitoring and under a range of hydrologic conditions at the two streamflow-measurement stations in Delaware as part of State monitoring efforts. Evaluation of the limited data collected and simulated results under base-flow conditions do not indicate a bias in the simulation (fig. 24). However, for the larger amount of data collected under State monitoring, the model appears to undersimulate chlorophyll a at higher concentrations (fig. 25). The highest concentration of chlorophyll *a* was measured in the samples at Wooddale and Stanton collected under the highest flow conditions of all samples and may include chlorophyll *a* from sources (such as periphyton) disturbed by high-flow conditions.

Samples for BOD analysis were collected under stormflow and base-flow conditions in 1998 at the nonpoint-source monitoring site, 01480000 Red Clay Creek at Wooddale, Del. Comparison of simulated and observed BOD loads under stormflow conditions indicates that both simulated stormflow and BOD are less than observed stormflow and BOD for the five storms sampled and that the undersimulation for BOD is up to 23 percent

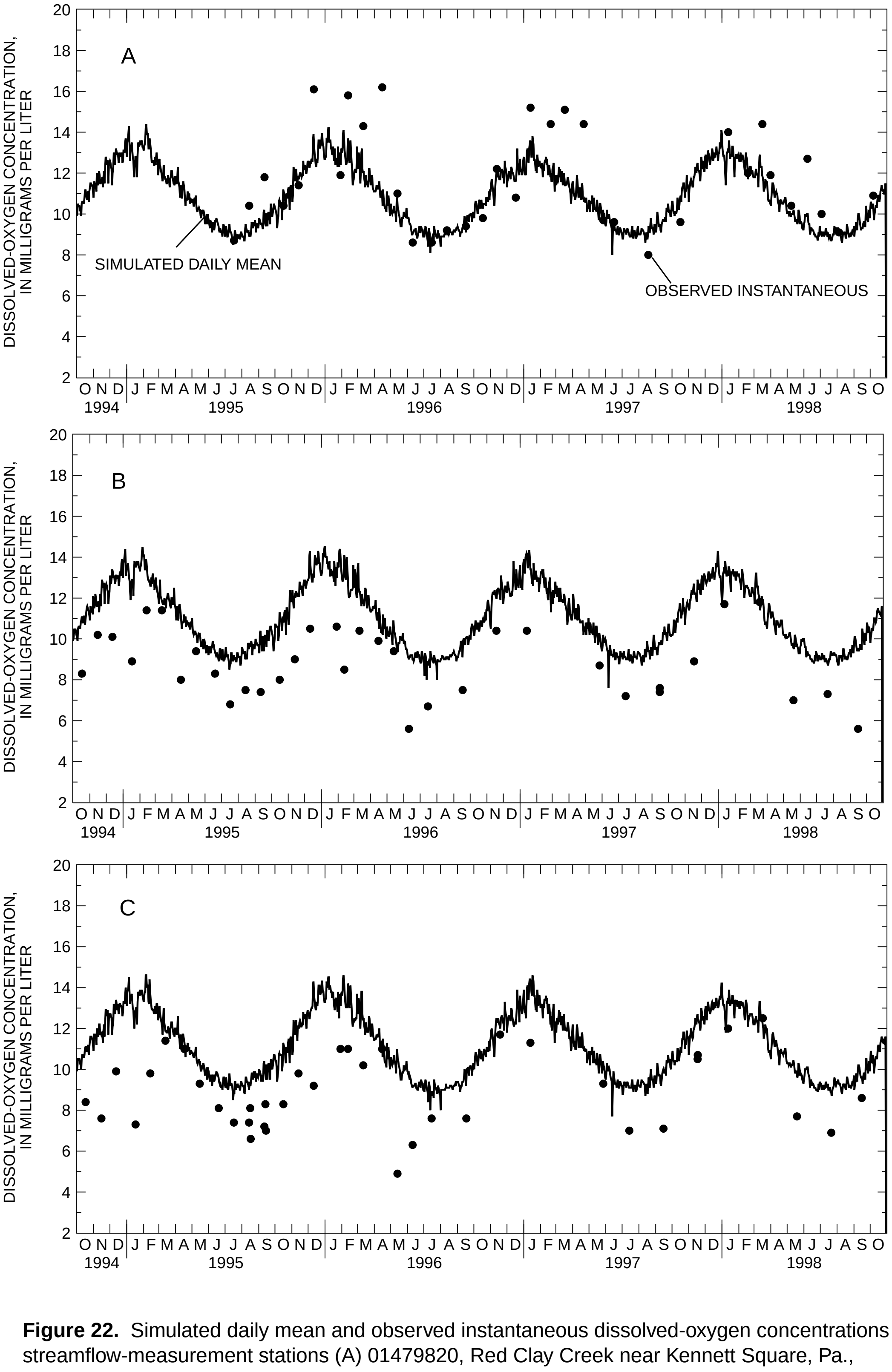

Figure 22. Simulated daily mean and observed instantaneous dissolved-oxygen concentrations at streamflow-measurement stations (A) 01479820, Red Clay Creek near Kennett Square, Pa., (B) 01480000, Red Clay Creek at Wooddale, Del., and (C) 01480015, Red Clay Creek at Stanton, Del., October 1994 through October 1998.

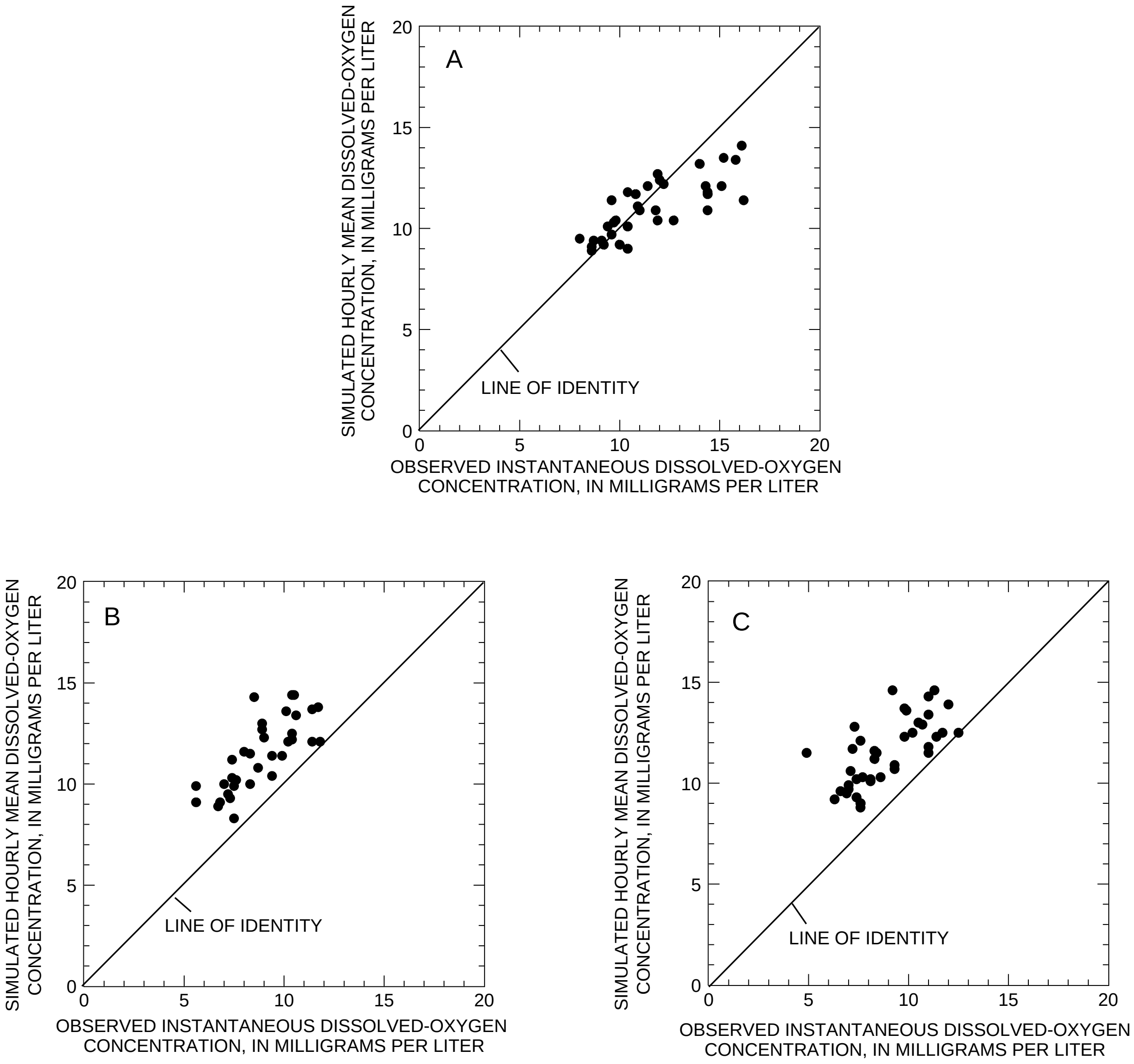

Figure 23. Simulated hourly mean and observed instantaneous dissolved-oxygen concentrations at streamflow-measurement stations (A) 01479820, Red Clay Creek near Kennett Square, Pa., (B) 01480000, Red Clay Creek at Wooddale, Del., and (C) 01480015, Red Clay Creek at Stanton, Del., October 1994 through October 1998. (Data from Pennsylvania Department of Environmental Protection and Delaware Department of Environmental Control.)

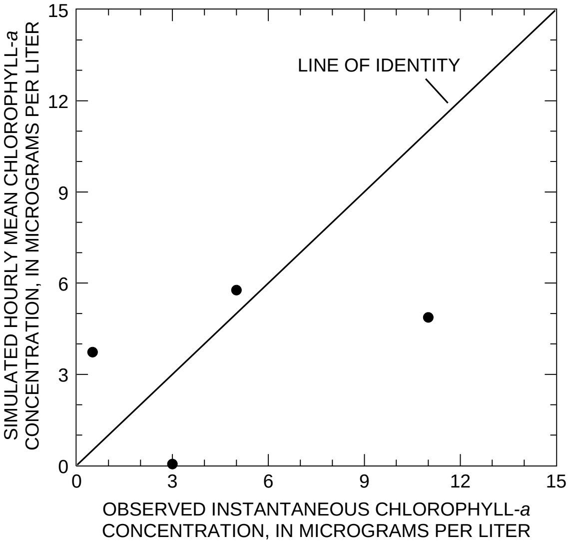

Figure 24. Simulated and observed concentrations of chlorophyll *a* in base-flow samples at streamflow-measurement station 01480000 Red Clay Creek at Wooddale, Del., 1998.

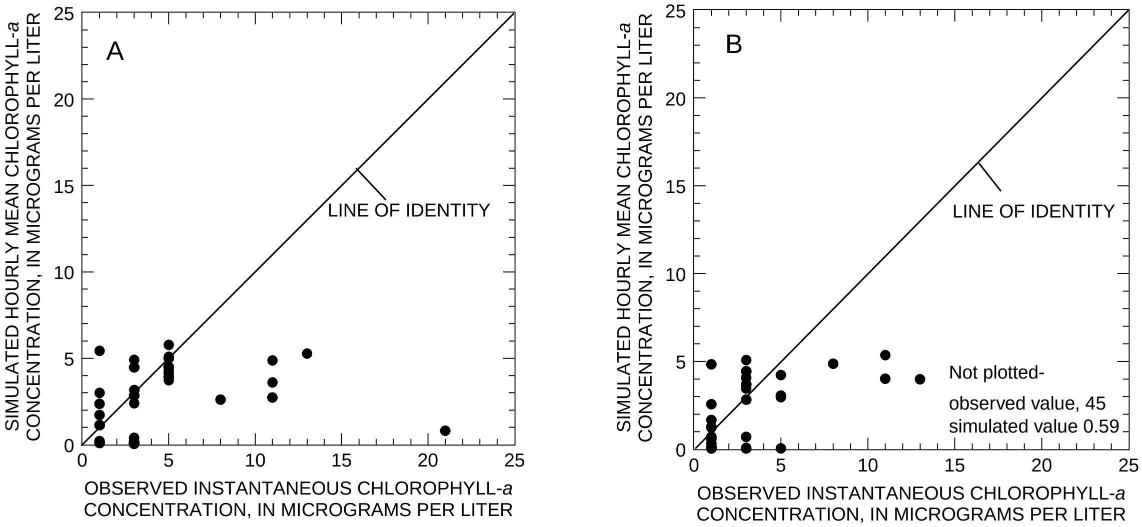

Figure 25. Simulated hourly mean and observed instantaneous concentrations of chlorophyll *a* at streamflow-measurement stations (A) 01480000 Red Clay Creek at Wooddale, Del., and (B) 01480015, Red Clay Creek at Stanton, Del., October 1994 through October 1998. (Data from Pennsylvania Department of Environmental Protection and Delaware Department of Environmental Control.)

greater than the undersimulation for streamflow (table 19). Undersimulation of BOD may result in undersimulation of BOD decay and consequent underestimation of oxygen depletion. The amount of oxygen in the stream reach can affect the extent of nitrification and denitrification reactions. No bias in the simulation of BOD under base-flow conditions was apparent for the limited number of samples (fig. 26). Concentrations of BOD in some of the samples collected in 1998 under base-flow conditions were reported as less than the detection level of 2.4 mg / L and were estimated for analysis to be 1.2 mg / L, 0.5 times the detection level (fig. 26).

Data collected by PADEP and DNREC at three streamflow-measurement stations under a range of hydrologic conditions also were used to evaluate the simulation of BOD. As noted earlier, most of the samples were collected under moderate or base-flow conditions. The median difference between simulated and observed BOD concentrations was 20 percent for Red Clay Creek near Kennett Square, -28 percent for Red Clay Creek at Wooddale, and -32 percent for Red Clay Creek near Stanton (fig. 27). This pattern of differences

Table 19. *Simulated and observed streamflow and loads of biochemical oxygen demand for storms sampled in 1998 at the nonpoint-source monitoring site, 01480000 Red Clay Creek at Wooddale, Del.*

[BOD, biochemical oxygen demand; ft^3/s, cubic feet per second]

Dates of storm sampling	Peak discharge[1] (ft^3/s)	Streamflow volume (millions of cubic feet)			BOD load (tons)		
		Simulated	Observed	Percentage difference[2]	Simulated	Observed	Percentage difference[2]
March 8-9	688	14.68	19.33	-24	2.43	3.18	-23
May 2-3	66	7.45	7.62	-2	.79	.86	-8
June 12	580	3.05	7.38	-59	.46	1.90	-76
July 8-9	280	7.77	9.11	-15	1.40	2.12	-34
October 8-9	74	4.20	5.68	-26	.70	1.12	-38
Total (all storms)		37.16	49.11	-25	5.78	9.18	-37

[1] Peak mean hourly discharge during period of composite sampling.

[2] 100 x (simulated-observed)/observed.

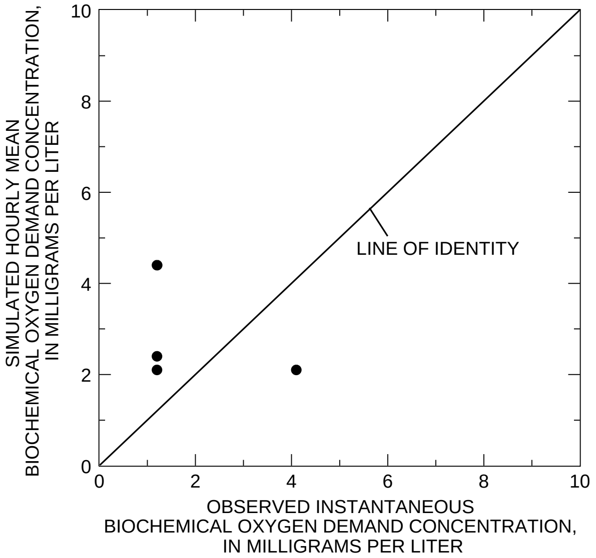

Figure 26. Simulated and observed concentrations of 20-day biological oxygen demand in base-flow samples at streamflow-measurement station 01480000 Red Clay Creek at Wooddale, Del., 1998.

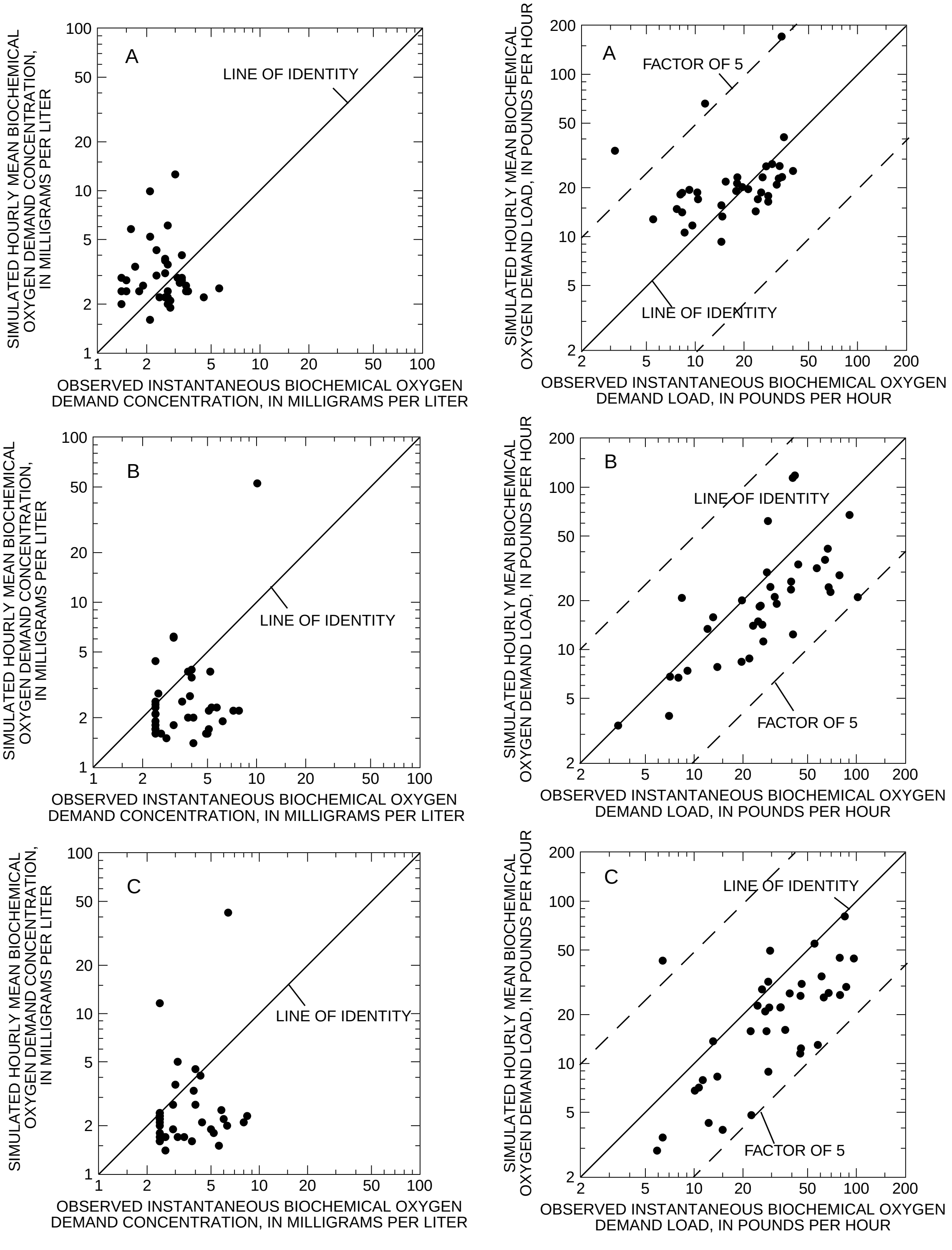

Figure 27. Simulated hourly mean and observed instantaneous 20-day biochemical oxygen demand concentrations and loads at streamflow-measurement stations (A) 01479820, Red Clay Creek near Kennett Square, Pa., (B) 01480000, Red Clay Creek at Wooddale, Del., and (C) 01480015, Red Clay Creek at Stanton, Del., October 1994 through October 1998. (Data from Pennsylvania Department of Environmental Protection and Delaware Department of Environmental Control.)

between simulated and observed concentrations is the converse of the dissolved-oxygen simulation. Apparent errors in BOD and dissolved-oxygen simulations may result, in part, from the inverse relation between BOD and dissolved-oxygen concentration. Errors in load estimates of BOD from point sources as well as nonpoint sources may contribute to overall errors of BOD in-stream concentrations.

Overall, the simulation of oxygen-related constituents results in fair to good estimates of dissolved oxygen concentrations that are needed for the in-stream simulation of nutrients. Errors in the simulation of BOD and plankton affect the simulation of in-stream dissolved-oxygen concentrations. Undersimulation of BOD could result in oversimulation of dissolved-oxygen concentration. Undersimulation of plankton could result in the undersimulation of dissolved-oxygen concentration during the day, when photosynthesis occurs, and oversimulation of dissolved oxygen during the night, when respiration processes are dominant.

Nitrogen

The two inorganic species of nitrogen, nitrate and ammonia, were simulated. Nitrogen loads from point and nonpoint sources were included in the simulation. Loads from point-source discharges were estimated from reported average monthly data for input on an hourly time step to the model. For most point-source discharges, nitrate was estimated from reported ammonia loads using the ratios specified in U.S. Environmental Protection Agency Region 3 (2000a), whereas nitrite was assumed to be negligible. The ratio of nitrate to ammonia in point-source effluent used for model data sets was 0.84 for small wastewater-treatment plants (WWTPs) (generally discharging less than 0.5 Mgal / d), 314 for advanced secondary treatment type 1 WWTPs, 157 for advanced secondary treatment type 2 WWTPs, and 0.21 for industrial discharges. In the Red Clay Creek Basin, all WWTPs were considered small plants (U.S. Environmental Protection Agency Region 3, 2000a). For nonpoint sources, concentrations of nitrate and ammonia in sediment (soil), interflow, and ground water were estimated as fixed concentrations that differed by land use. Nitrate was assumed to be transported solely in the dissolved form. Ammonia was assumed to be transported in both dissolved and adsorbed forms.

Water-quality data from the nonpoint-source monitoring station, 01480000 Red Clay Creek at Wooddale, Del., were used in the calibration of concentrations of dissolved nitrate and dissolved and particulate ammonia nitrogen in stormflow and base flow. Simulated and observed concentrations of dissolved nitrate for the five storms sampled at the nonpoint-source monitoring site are shown in figure 28. Composite samples were collected for all five storms but discrete samples only were collected for three storms (March, July, and October 1998). Observed and simulated nitrate concentrations generally decrease as streamflow increases during storms, although in two storms (July and October) simulated decreases in nitrate concentrations were larger than observed decreases in nitrate concentrations (fig. 28).

Data from composite stormflow samples collected in 1998 were used in the calculation of loads of dissolved nitrate and dissolved and particulate ammonia nitrogen. Calculated loads served as the observed values in overall evaluation of nitrogen transport during storms.

Simulated and observed streamflow and load data for dissolved nitrate for sampled storm events are presented in table 20. For the sampled storm periods, streamflow volume and nitrate loads tend to be undersimulated. The difference between observed and simulated streamflow ranged from -2 to -59 percent for individual storms and was -24 percent for the total of all storms. The difference between observed and simulated dissolved nitrate loads ranged from -17 to -81 percent for individual storms and was -41 percent for the total of all storms. As discussed in the section on sediment, some error in load simulations is due to error in streamflow simulation and the difference between the load error and the streamflow-volume error may be useful in evaluating the water-quality component of the overall load error. The cumulative error of -41 percent for simulated nitrate load adjusted for the cumulative error of -24 percent for simulated streamflow volume at Wooddale is -22 percent. At the monitoring site at Wooddale on Red Clay Creek, the undersimulation of nitrate may be related to errors in estimating contributions of nitrate from point sources in addition to those associated with nitrate from nonpoint sources.

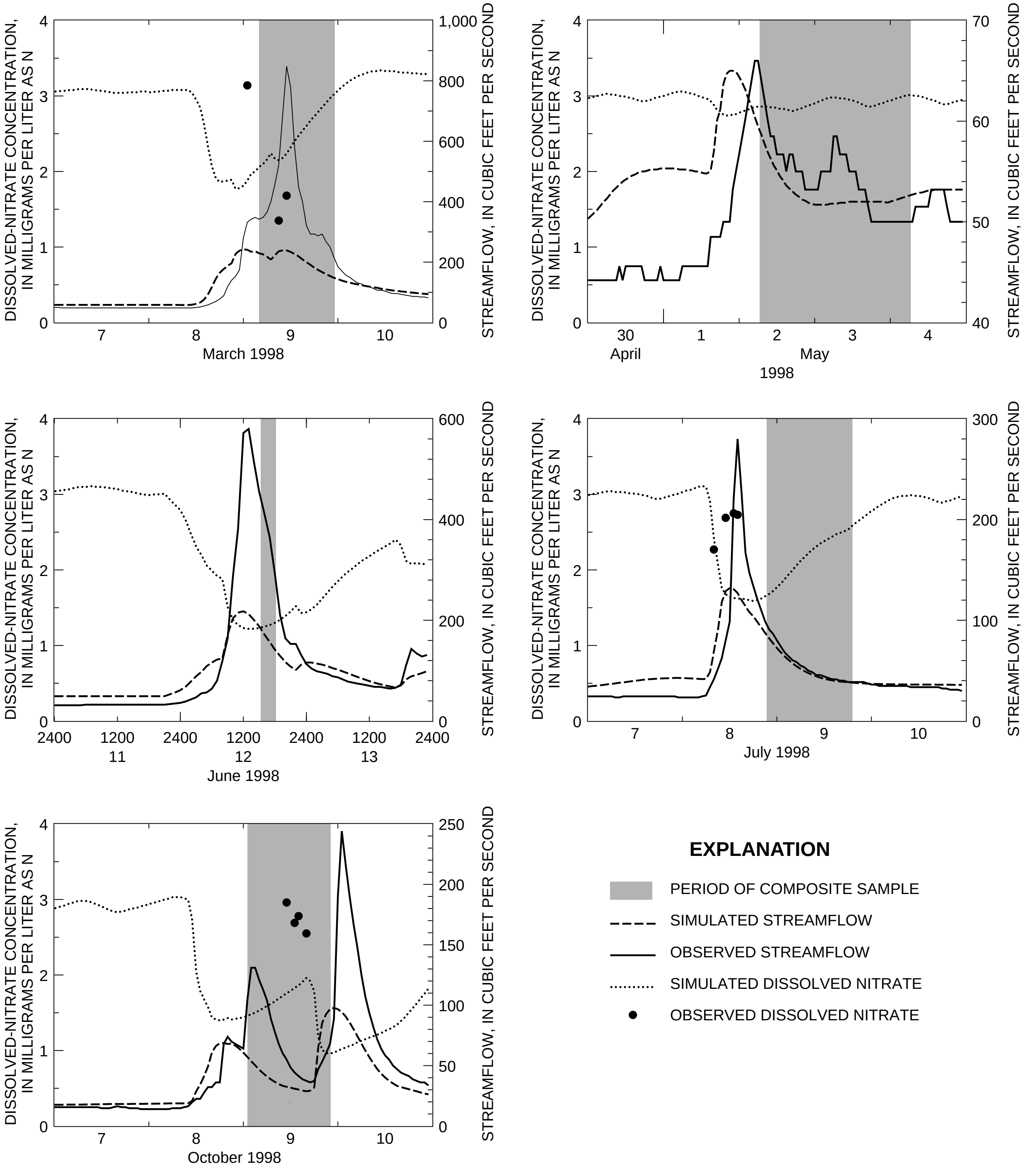

Figure 28. Simulated and observed streamflow and dissolved-nitrate concentrations and period of composite sample during five storms in 1998 at streamflow-measurement station 01480000, Red Clay Creek at Wooddale, Del.

Table 20. *Simulated and observed streamflow and loads of dissolved nitrate, dissolved ammonia, and particulate ammonia for storms sampled in 1998 at the nonpoint-source monitoring site, 01480000 Red Clay Creek at Wooddale, Del.*

[ft^3/s, cubic feet per second; --, not calculated; mg/L, milligrams per liter]

Dates of storm sampling	Peak flow[1] (ft^3/s)	Streamflow volume (millions of cubic feet)			Dissolved nitrate load (pounds as nitrogen)			Dissolved ammonia load (pounds as nitrogen)			Particulate ammonia load (pounds as nitrogen)		
		Simulated	Observed	Percent difference[2]	Simulated	Observed	Percent difference[2]	Simulated	Observed	Percent difference[2]	Simulated	Observed	Percent difference[2]
March 8-9	688	14.68	19.33	-24	1,907	2,711	-30	102	109	-7	14.1	[3]0.0	--
May 2-3	66	7.45	7.62	-2	1,351	1,627	-17	40.7	13.5	202	.75	9.14	-92
June 12	580	3.05	7.38	-59	241	1,283	-81	9.4	18.7	-50	.52	6.53	-92
July 8-9	280	7.77	9.11	-15	867	1,359	-36	35.5	36.3	-2	.68	6.91	-90
October 8-9	74	4.20	5.68	-26	410	1,156	-65	26.3	[4]1.8	1,368	.55	[5]17.23	-97
Total (all storms)		37.16	49.11	-24	4,776	8,136	-41	214	179	19	16.6	39.81	-58

[1] Peak mean hourly discharge during period of composite sampling.

[2] 100 x (simulated-observed)/observed.

[3] Reported total ammonia concentration of less than dissolved ammonia concentration in composite storm sample is questionably low.

[4] Reported dissolved ammonia concentration of less than 0.005 mg/L in composite storm sample is questionably low.

[5] Reported total ammonia concentration of 0.048 mg/L in composite storm sample is questionably high relative to dissolved ammonia concentration.

Simulated concentrations of dissolved nitrate in base flow were within 0.2 mg/L or 13 percent of observed concentrations at the nonpoint-source monitoring site at Wooddale, Del. (fig. 29). Streamflow was well simulated for all base-flow samples, as shown in figure 19. The monitoring site at Wooddale is downstream of point-source discharges that can affect concentrations of nitrate and other constituents. Observed hourly concentrations of nitrate for point-source discharges were not available but were interpolated from reported average monthly concentrations of ammonia assuming a constant ratio of nitrate to ammonia. The ratio of nitrate to ammonia in effluent probably fluctuates through time.

Data on nitrate concentrations at sites upstream of major point-source discharges were collected through county and State monitoring programs (table 7). These data indicate the nitrate concentrations tend to be undersimulated at the West Branch Red Clay Creek at Kennett Square site (average difference was -30 percent), adequately simulated at the East Branch near Five Points site (average difference was 0 percent), and oversimulated at the Burroughs Run site (average difference was 63 percent). Sites on the West and East Branches of Red Clay Creek were sampled under base-flow condition and the Burroughs Run site

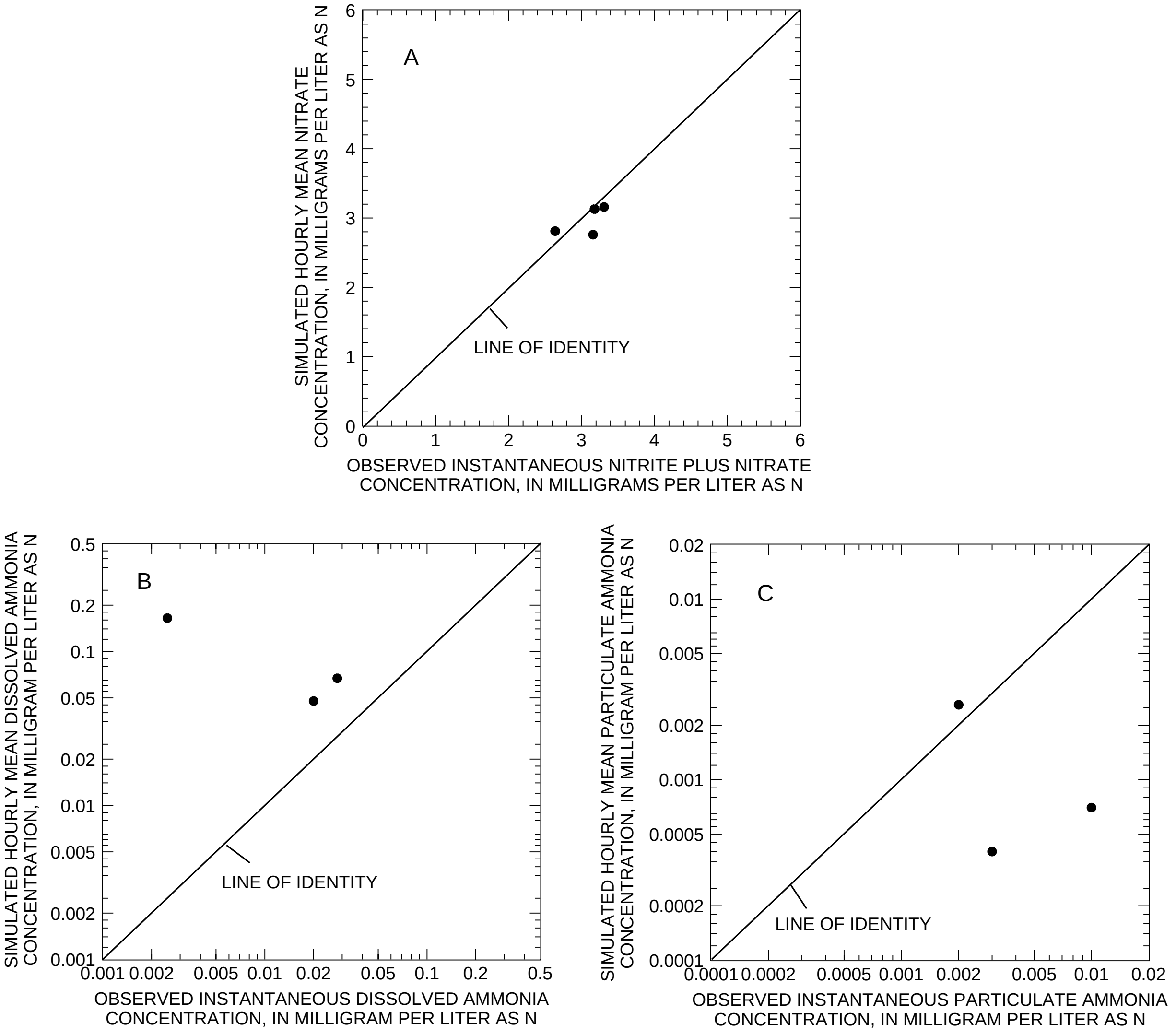

Figure 29. Simulated and observed concentrations of (A) nitrate, (B) dissolved ammonia, and (C) particulate ammonia during base-flow conditions in 1998 at streamflow-measurement station 01480000 Red Clay Creek at Wooddale, Del.

was sampled under a range of hydrologic conditions. These results suggest that the ground-water contribution of nitrate is larger than simulated for the West Branch drainage area and less than simulated for the Burroughs Run drainage area.

Data collected by PADEP and DNREC at three streamflow-measurement stations under a range of hydrologic conditions also were used to evaluate the simulation of nitrate. All three of the sites are downstream of point-source discharges. As noted earlier, most of the samples were collected under moderate or base-flow conditions (fig. 20). Observed nitrate concentrations tend to decrease downstream from Kennett Square to Wooddale to Stanton, possibly because of dilution or instream nitrate uptake. The average difference between simulated and observed nitrate concentrations was -20 percent for Red Clay Creek near Kennett Square, 5 percent for Red Clay Creek at Wooddale, and 2 percent for Red Clay Creek near Stanton. Nitrate concentrations tend to be undersimulated at Red Clay Creek near Kennett Square and oversimulated at the downstream stations, Red Clay Creek at Wooddale and Red Clay Creek near Stanton (fig. 30). Errors in load estimates of nitrate from point sources and nonpoint sources as well as instream processes may contribute to overall errors of instream nitrate concentrations. At all sites, simulated nitrate loads generally were within a factor of 5 or less of observed loads (fig. 30).

Simulated concentrations of dissolved and particulate ammonia were compared to observed concentrations of dissolved and particulate ammonia in stormflow, and base-flow conditions where observed particulate ammonia concentrations were calculated by subtracting dissolved-ammonia concentrations from total ammonia concentrations. Review of 1998 monitoring data indicates that, on average, dissolved ammonia represents about 71 percent of total ammonia concentrations for samples collected at Red Clay Creek at Wooddale.

Simulated and observed concentrations of dissolved and particulate ammonia for the five storms sampled at the nonpoint-source monitoring site, Red Clay Creek at Wooddale, are shown in figures 31 and 32. Composite samples were collected for all five storms but discrete samples only were collected for three storms (March, July, and October 1998). Observed concentrations of dissolved ammonia generally tend to increase as streamflow increases during storms but simulated concentrations of ammonia appear to fluctuate more in response to changes in time than streamflow (fig. 31). The temporal pattern of fluctuations in simulated dissolved-ammonia concentrations probably is related to the simulated processes of ammonia uptake and release by periphyton and phytoplankton. The available nonpoint-source monitoring data are insufficient to calibrate the effects of algal growth and respiration on instream dissolved-ammonia concentrations, and the algal (periphyton and phytoplankton) simulation is a source of error for the dissolved-ammonia simulation. Observed and simulated concentrations of particulate ammonia also tend to increase as streamflow increases during storms (fig. 32). Although the general range of observed dissolved and particulate ammonia concentrations during storms is simulated in the model, errors or differences between observed and simulated concentrations are apparent. Errors or differences between observed and simulated particulate ammonia concentrations are due in part to errors in flow, suspended-sediment simulation, and timing of rainfall for storms.

Data from composite stormflow samples collected in 1998 were used in the calculation of loads of dissolved nitrate, and dissolved and particulate ammonia nitrogen. Calculated loads served as the observed values in overall evaluation of nitrogen transport during storms. Simulated and observed streamflow and loads of dissolved and particulate ammonia nitrogen for storm events in 1998 are presented in table 20. Observed loads of dissolved ammonia commonly are greater than observed loads of particulate ammonia except for one storm in October 1998, for which the particulate ammonia was greater than the dissolved ammonia load. The analytical results for the ammonia concentrations in the October composite storm sample are questionable, however, partly because of the unusual ratio of observed total dissolved ammonia. For all five storms, streamflow was undersimulated. For three storms sampled, dissolved ammonia was undersimulated. The difference between observed and simulated streamflow ranged from -2 to -59 percent for individual storms and was -24 percent for the total of all storms. The difference between observed and dissolved ammonia loads ranged from -50 to 1,368 percent for individual storms and was 19 percent for the total of all storms. The maximum values in percent differences are associated with storm samples with questionable analytical results. Adjusting for the cumulative error of -24 percent for simulated

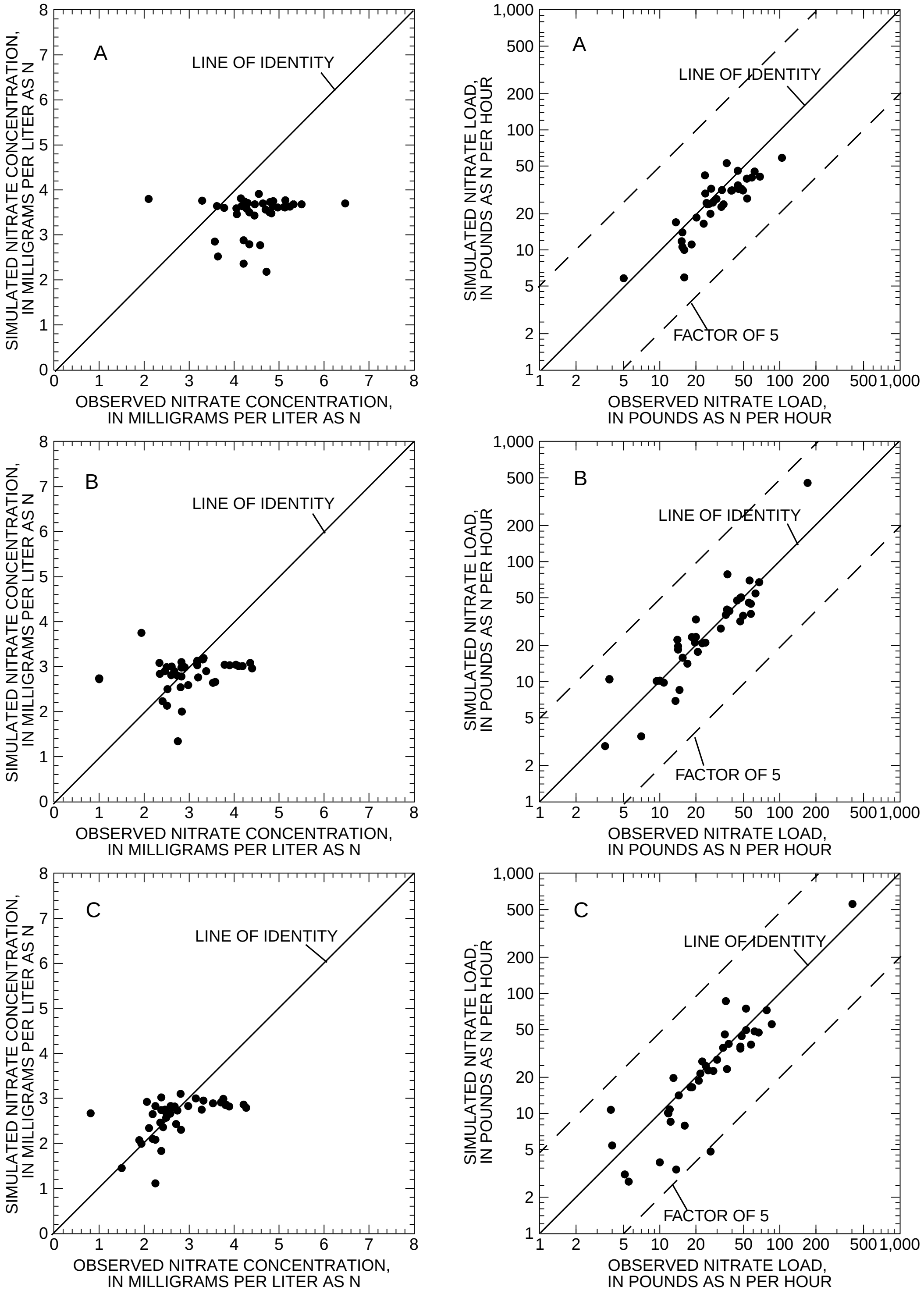

Figure 30. Simulated hourly mean and observed instantaneous nitrate concentrations and loads at streamflow-measurement stations (A) 01479820, Red Clay Creek near Kennett Square, Pa., (B) 01480000, Red Clay Creek at Wooddale, Del., and (C) 01480015, Red Clay Creek at Stanton, Del., October 1994 through October 1998. (Data from Pennsylvania Department of Environmental Protection and Delaware Department of Environmental Control.)

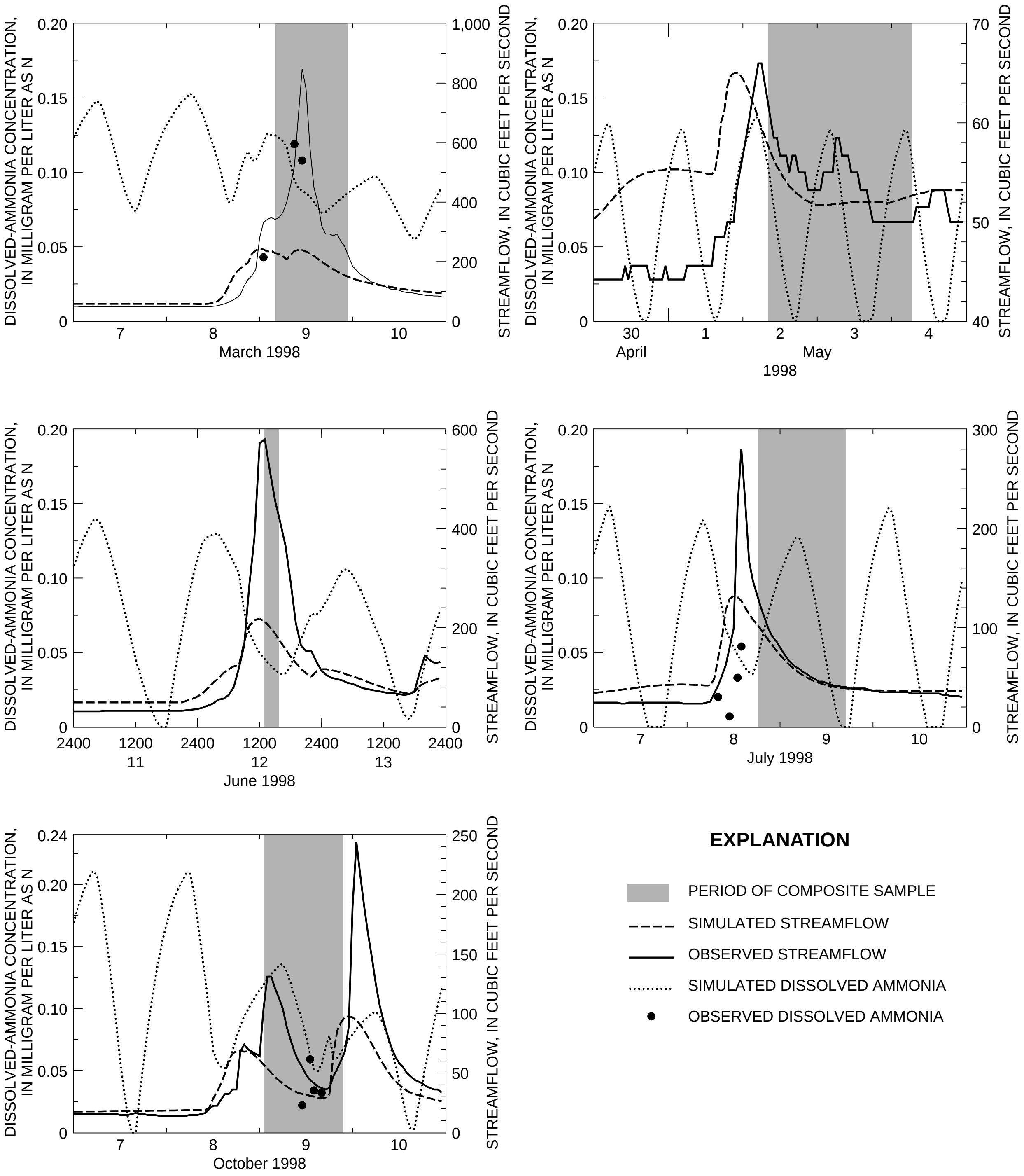

Figure 31. Simulated and observed streamflow and dissolved-ammonia concentrations and period of composite sample during five storms in 1998 at streamflow-measurement station 01480000, Red Clay Creek at Wooddale, Del.

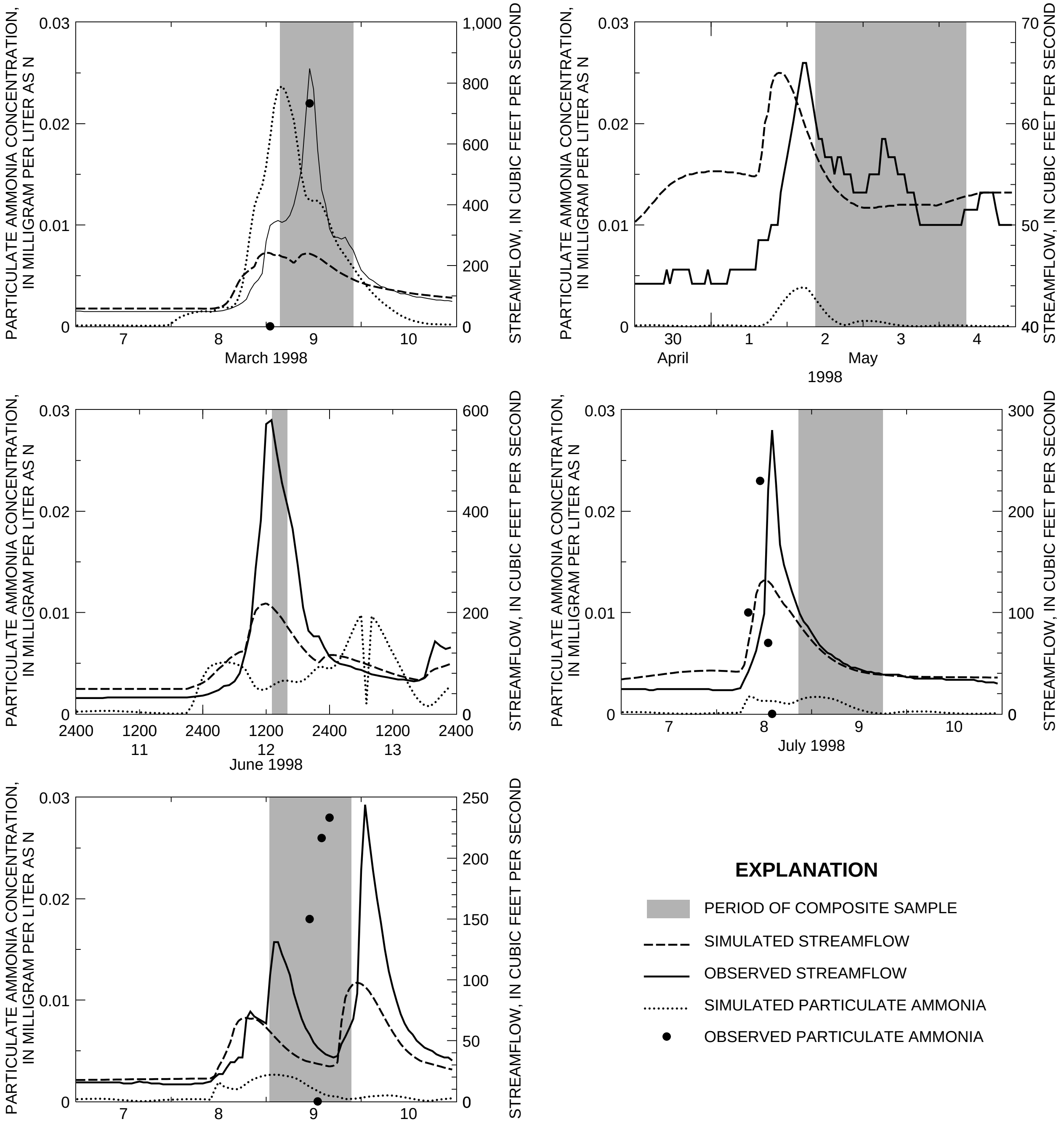

Figure 32. Simulated and observed streamflow and particulate ammonia concentrations and period of composite sample during five storms in 1998 at streamflow-measurement station 01480000, Red Clay Creek at Wooddale, Del.

streamflow, as discussed in the section on sediment, the 19-percent cumulative error for simulated dissolved-ammonia loads at Wooddale indicates a cumulative error of 58 percent associated with the simulation of dissolved ammonia for the five storms. At the monitoring site at Wooddale on Red Clay Creek, the oversimulation and undersimulation of dissolved-ammonia concentrations may be related to analytical errors and errors in estimating contributions of ammonia from point sources in addition to those associated with nitrate from nonpoint sources.

For four storms sampled, particulate ammonia was undersimulated (table 20). The difference between observed and particulate ammonia loads ranged from -97 to -90 percent for individual storms and was -58 percent for the total of all storms. Adjusting for the cumulative error of -24 percent for simulated streamflow, the cumulative error of -58 percent for simulated particulate ammonia loads at Wooddale indicates a cumulative error of -45 percent associated with the simulation of particulate ammonia for the five storms. The undersimulation of particulate ammonia may be related to errors in partitioning from dissolved to sorbed phases and to errors in sediment transport. Using monthly or yearly annual load criteria (Donigian and others, 1984), the dissolved and particulate ammonia calibration ranges from “very good” to worse than “fair” for individual storms.

Simulated concentrations of dissolved ammonia under base-flow conditions generally were greater than observed concentrations by 0.028 to 0.163 mg/L as nitrogen (N) at the Wooddale monitoring site (fig. 29). As noted previously, streamflow was well simulated for all base-flow samples (fig. 19). The oversimulation of dissolved ammonia at the Wooddale site may be related to the lack of temporal resolution in estimated ammonia concentrations in discharges from WWTPs upstream and to inaccurate simulation of instream processes that include ammonia uptake and release by algae. Mean hourly ammonia loads for point-source discharges were estimated from reported average monthly ammonia values; however, hourly values probably vary within each month. Simulated concentrations of particulate ammonia were less than 0.005 mg/L as N at all six sites and are less than the observed concentrations of particulate ammonia, which ranged from 0.002 to 0.01 mg/L as N.

Data collected by PADEP and DNREC at three streamflow-measurement stations under a range of hydrologic conditions also were used to evaluate the simulation of total ammonia. All three of the sites are downstream from point-source discharges. As noted earlier, most of the samples were collected under moderate or base-flow conditions (fig. 20). Ammonia concentrations are not well simulated. The average difference between simulated and observed total ammonia concentrations was 653 percent for Red Clay Creek near Kennett Square, 295 percent for Red Clay Creek at Wooddale, and 319 percent for Red Clay Creek near Stanton. Total-ammonia concentrations tend to be oversimulated at all three sites at lower concentrations (fig. 33). Errors in load estimates of nitrate from point sources and nonpoint sources as well as instream processes may contribute to overall errors of instream ammonia concentrations. At all sites, simulated ammonia loads generally were within a factor of 10 or less of observed loads (fig. 33).

Overall, the nitrate and dissolved and particulate ammonia simulation under base-flow and stormflow conditions generally appears to represent the observed patterns of ammonia concentrations in response to flow conditions and defined land uses. Nitrate concentrations and loads were simulated better than the ammonia concentrations and loads in the HSPF model. Based on the criteria of Donigian and others (1984), the overall simulation of nitrate was “good,” and the overall simulation of dissolved and particulated ammonia was “fair” to “worse than fair.” Dissolved ammonia storm loads and base-flow concentrations tend to be oversimulated at the whole-basin site (Red Clay Creek at Wooddale) that is downstream from various point-source discharges and this oversimulation partly may be related to inaccurate characterization of ammonia uptake upstream of the sampling site and (or) inadequate characterization of ammonia in discharges. Commonly, for the Red Clay Creek model, errors expressed in percent are greater for particulate ammonia simulation than for dissolved ammonia simulation and are greater for the ammonia simulation than the nitrate simulation. Of the nitrogen species simulated, nitrate represents the greatest amount and particulate ammonia represents the least amount of the inorganic nitrogen load. In storms, nitrate loads are an order of magnitude greater than dissolved-ammonia loads and two orders of magnitude greater than particulate ammonia loads (table 20).

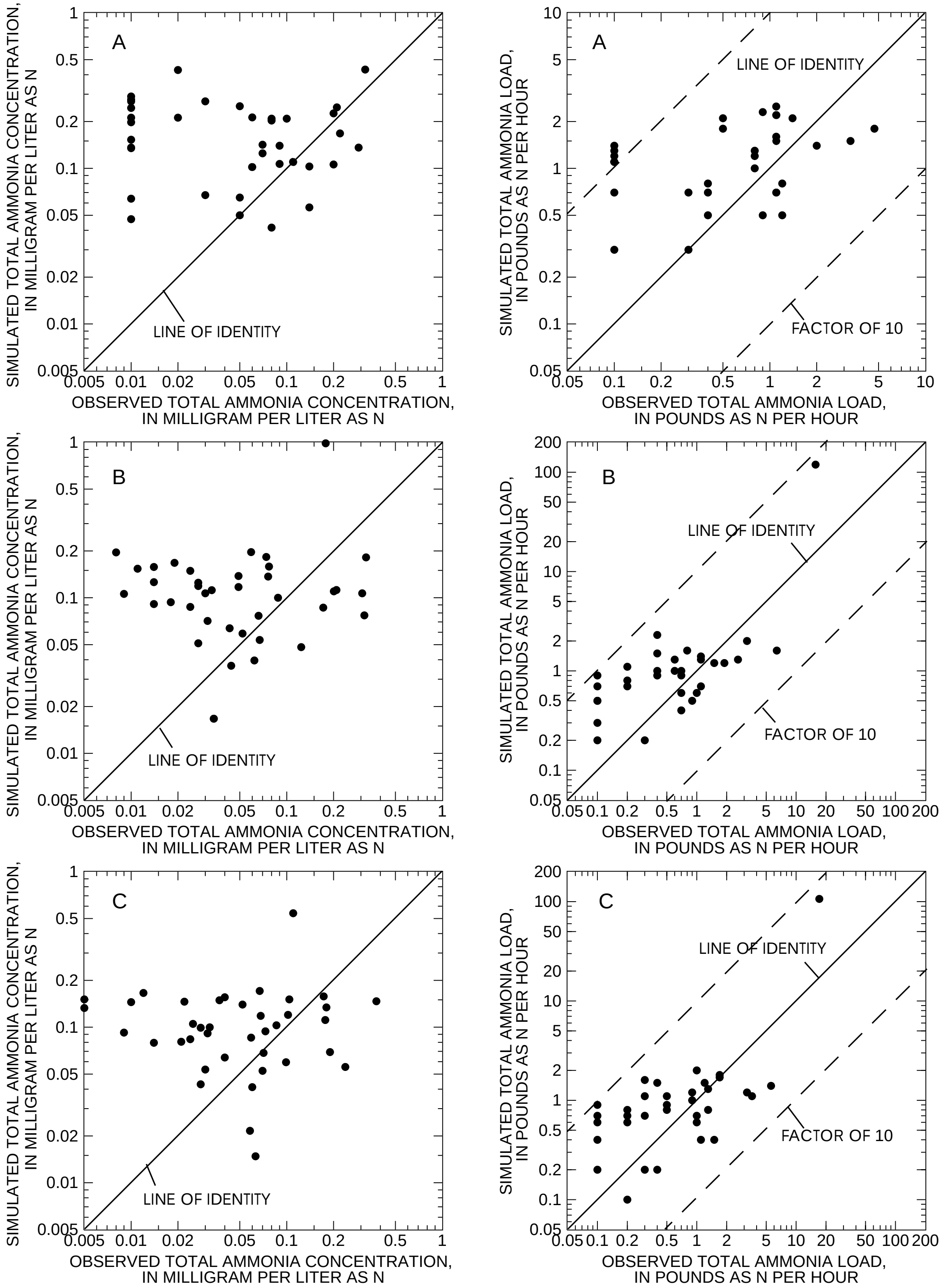

Figure 33. Simulated hourly mean and observed instantaneous total ammonia concentrations and loads at streamflow-measurement stations (A) 01479820, Red Clay Creek near Kennett Square, Pa., (B) 01480000, Red Clay Creek at Wooddale, Del., and (C) 01480015, Red Clay Creek at Stanton, Del., October 1994 through October 1998. (Data from Pennsylvania Department of Environmental Protection and Delaware Department of Environmental Control.)

Simulated annual yields of nitrogen varied by land use. Annual yields of nitrate and ammonia are presented per land-use category per segment in tables 21 and 23 and mean yields of nitrate and ammonia for the simulation period are presented per land-use category per segment in tables 22 and 24. For most land uses, simulated nitrate yields generally are at least one order of magnitude greater than simulated total ammonia yields.

Phosphorus

The model was used to simulate inorganic phosphorus, where dissolved and adsorbed orthophosphate are considered to be the principal dissolved and particulate inorganic phosphorus species. Phosphorus loads from point and nonpoint sources are included in the simulation. Loads from point-source discharges were estimated from reported monthly average values for input on an hourly time step to the model. For nonpoint sources, dissolved and particulate phosphorus were estimated at fixed concentrations in sediment (soil), interflow, and ground water that differed by land use. Phosphorus was assumed to be transported in both dissolved and adsorbed forms from the land surface and in the stream channel. Review of 1994-98 DNREC monitoring data on the mainstem of Red Clay Creek collected typically under moderate-flow conditions indicates that, on average, dissolved orthophosphate represents about 70 percent of total phosphorus concentrations. For 1998 data collected at the Wooddale nonpoint-source monitoring station under a range of flow conditions, dissolved orthophosphate represented, on average, about 41 percent of total phosphorus concentrations.

Water-quality data from the nonpoint-source monitoring station, Red Clay Creek at Wooddale, were used to assess the calibration of dissolved and particulate (adsorbed) orthophosphate. Observed concentrations of particulate orthophosphate were estimated by subtracting dissolved-phosphorus concentrations from total-phosphorus concentrations and assuming the difference was particulate orthophosphate.

Simulated and observed dissolved and particulate orthophosphate concentrations are shown in figures 34 and 35 for the five storms sampled at the nonpoint-source monitoring site, Red Clay Creek at Wooddale. Composite samples were collected for all five storms but discrete samples only were collected for three storms (March, July, and October 1998). Samples from the October 1998 storm were not analyzed for total phosphorus and, therefore, particulate phosphorus concentrations could not be estimated. Observed dissolved and particulate orthophosphate concentrations generally tend to increase as streamflow increases during storms (figs. 34 and 35). The general pattern of observed dissolved and particulate orthophosphate concentrations during storms are simulated by the model only for some storms.

Table 21. *Observed annual precipitation and simulated annual nitrate yields by land use for the three segments of the Hydrological Simulation Program–Fortran (HSPF) model for Red Clay Creek Basin, 1995-97*

	Segment	Year			
		1995	1996	1997	1995-97 average
Precipitation (inches)[1]	7,4,6	40.59	61.98	35.01	45.86
Simulated annual nitrate yield (pounds as nitrogen per acre per year), by land-use category[2]					
Residential - unsewered	7	7.03	18.6	11.8	12.5
Residential -sewered	7	3.78	9.89	6.12	6.60
Urban	7	3.93	9.58	6.05	6.52
Agricultural - animal/crop	7	15.0	35.5	22.0	24.2
Agricultural - row crop	7	13.1	31.0	18.9	21.0
Agricultural - mushroom	7	17.8	42.7	24.8	28.4
Forested	7	.728	2.11	1.39	1.41
Open	7	2.61	6.92	4.31	4.61
Wetlands/water	7	.741	2.25	1.47	1.49
Undesignated	7	2.53	6.93	4.32	4.59
Impervious - residential	7	2.03	2.06	2.03	2.04
Impervious - urban	7	2.03	2.06	2.03	2.04
Simulated annual nitrate yield (pounds as nitrogen per acre per year), by land-use category[2]					
Residential - unsewered	4	7.06	19	10.7	12.3
Residential -sewered	4	3.81	10.3	5.65	6.59
Urban	4	3.93	9.95	5.55	6.48
Agricultural - animal/crop	4	14.4	36.5	19.8	23.6
Agricultural - row crop	4	8.89	22.8	12.0	14.6
Agricultural - mushroom	4	17.6	43.7	22.7	28.0
Forested	4	.732	2.09	1.25	1.36
Open	4	2.56	7.09	3.92	4.52
Wetlands/water	4	.738	2.32	1.43	1.50
Undesignated	4	2.57	7.16	3.95	4.56
Impervious - residential	4	2.02	2.05	2.03	2.03
Impervious - urban	4	2.02	2.05	2.03	2.03
Simulated annual nitrate yield (pounds as nitrogen per acre per year), by land-use category[2]					
Residential - unsewered	6	9.09	22.1	8.52	13.2
Residential -sewered	6	4.77	11.8	4.42	7.00
Urban	6	4.86	11.7	4.43	7.00
Agricultural - animal/crop	6	17.3	42.1	15.9	25.1
Agricultural - row crop	6	14.7	36.2	13.5	21.5
Agricultural - mushroom	6	21.2	52.7	19.3	31.1
Forested	6	.896	2.36	.909	1.39
Open	6	3.23	7.94	2.98	4.72
Wetlands/water	6	.951	2.85	1.04	1.61
Undesignated	6	3.23	7.95	2.98	4.72
Impervious - residential	6	2.02	2.05	2.03	2.03
Impervious - urban	6	2.02	2.05	2.03	2.03

[1] Precipitation input to segment 7 = 0.85 x precipitation recorded at Coatesville.

[2] In pervious areas, unless noted.

Table 22. *Observed annual precipitation and simulated mean annual nitrate yield by land use for pervious and impervious land areas in the three segments of the Hydrological Simulation Program–Fortran (HSPF) model for Red Clay Creek Basin, 1995-97*

	1995-97 Average			
	Segment 7	**Segment 4**	**Segment 6**	**Mean of all segments**
Precipitation (inches)	[1]45.86	45.86	45.86	45.86
Simulated mean annual nitrate yield (tons as nitrogen per acre per year), by land-use category[2]				
Residential - unsewered	12.48	12.25	13.24	12.66
Residential -sewered	6.60	6.59	7.00	6.73
Urban	6.52	6.48	7.00	6.66
Agricultural - animals/crops	24.2	23.6	25.1	24.3
Agricultural - row crop	21.0	14.6	21.5	19.0
Agricultural - mushroom	28.4	28.0	31.1	29.2
Forested	1.41	1.36	1.39	1.39
Open	4.61	4.52	4.72	4.62
Wetlands/water	1.49	1.50	1.61	1.53
Undesignated	4.59	4.56	4.72	4.62
Impervious - residential	2.04	2.03	2.03	2.03
Impervious - urban	2.04	2.03	2.03	2.03

[1] Precipitation for segment 7 = 0.85 x precipitation at Coatesville 2 W.

[2] In pervious areas, unless where noted.

Table 23. *Observed annual precipitation and simulated annual total ammonia yields by land use for the three segments of the Hydrological Simulation Program–Fortran (HSPF) model for Red Clay Creek Basin, 1995-97*

	Segment	Year			
		1995	1996	1997	1995-97 average
Precipitation (inches)[1]	7,4,6	40.59	61.98	35.01	45.86
Simulated annual total ammonia yield (pounds as nitrogen per acre per year), by land-use category[2]					
Residential - unsewered	7	.088	.286	.109	.161
Residential -sewered	7	.050	.138	.060	.083
Urban	7	.068	.133	.065	.088
Agricultural - animal/crop	7	.764	1.430	.583	.926
Agricultural - row crop	7	.576	1.10	.443	.706
Agricultural - mushroom	7	3.15	6.31	1.61	3.69
Forested	7	.020	.055	.038	.037
Open	7	.073	.205	.106	.128
Wetlands/water	7	.012	.040	.024	.025
Undesignated	7	.070	.206	.106	.127
Impervious - residential	7	.370	.371	.372	.371
Impervious - urban	7	.431	.426	.432	.430
Simulated annual total ammonia yield (pounds as nitrogen per acre per year), by land-use category[2]					
Residential - unsewered	4	.083	.274	.097	.151
Residential -sewered	4	.047	.138	.054	.080
Urban	4	.063	.133	.058	.085
Agricultural - animal/crop	4	.489	1.110	.368	.656
Agricultural - row crop	4	.264	.624	.215	.368
Agricultural - mushroom	4	2.90	6.07	1.40	3.46
Forested	4	.020	.055	.034	.036
Open	4	.067	.204	.094	.122
Wetlands/water	4	.012	.040	.023	.025
Undesignated	4	.067	.204	.094	.122
Impervious - residential	4	.370	.370	.372	.371
Impervious - urban	4	.431	.426	.432	.430
Simulated annual total ammonia yield (pounds as nitrogen per acre per year), by land-use category[2]					
Residential - unsewered	6	.086	.242	.075	.134
Residential -sewered	6	.049	.143	.042	.078
Urban	6	.059	.147	.048	.085
Agricultural - animal/crop	6	.367	1.060	.309	.579
Agricultural - row crop	6	.214	.609	.181	.335
Agricultural - mushroom	6	1.05	3.72	.553	1.77
Forested	6	.024	.064	.024	.037
Open	6	.081	.214	.073	.123
Wetlands/water	6	.015	.048	.017	.027
Undesignated	6	.081	.213	.073	.122
Impervious - residential	6	.370	.370	.372	.371
Impervious - urban	6	.430	.426	.431	.429

[1] Precipitation for segment 7 = 0.85 x precipitation at Coatesville 2 W.

[2] In pervious areas, unless where noted.

Table 24. *Observed annual precipitation and simulated mean annual total ammonia yield for pervious and impervious land areas in the three segments of the Hydrological Simulation Program–Fortran (HSPF) model for Red Clay Creek Basin, 1995-97*

	1995-97 Average			
	Segment 7	**Segment 4**	**Segment 6**	**Mean of all segments**
Precipitation (inches)	[1] 45.86	45.86	45.86	45.86
Simulated mean annual total ammonia yield (tons as nitrogen per acre per year), by land-use category[2]				
Residential - unsewered	.161	.151	.134	.149
Residential -sewered	.083	.080	.078	.080
Urban	.088	.085	.085	.086
Agricultural - animals/crops	.926	.656	.579	.720
Agricultural - row crop	.706	.368	.335	.470
Agricultural - mushroom	3.69	3.46	1.77	2.97
Forested	.037	.036	.037	.037
Open	.128	.122	.123	.124
Wetlands/water	.025	.025	.027	.026
Undesignated	.127	.122	.122	.124
Impervious - residential	.371	.371	.371	.371
Impervious - urban	.430	.430	.429	.430

[1] Precipitation for segment 7 = 0.85 x precipitation at Coatesville 2 W.

[2] In pervious areas, unless where noted.

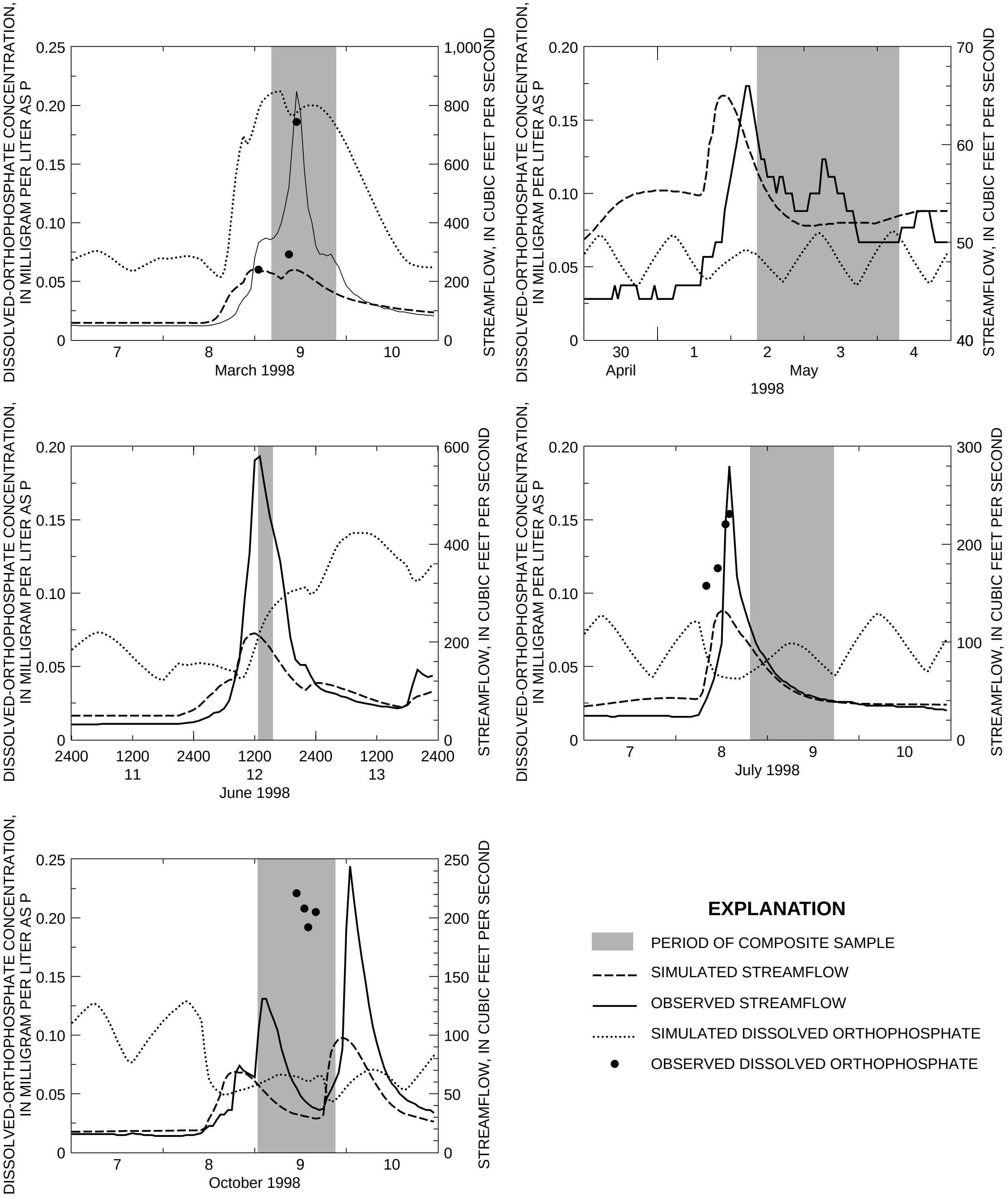

Figure 34. Simulated and observed streamflow and dissolved-orthophosphate concentrations and period of composite sample during five storms in 1998 at streamflow-measurement station 01480000, Red Clay Creek at Wooddale, Del.

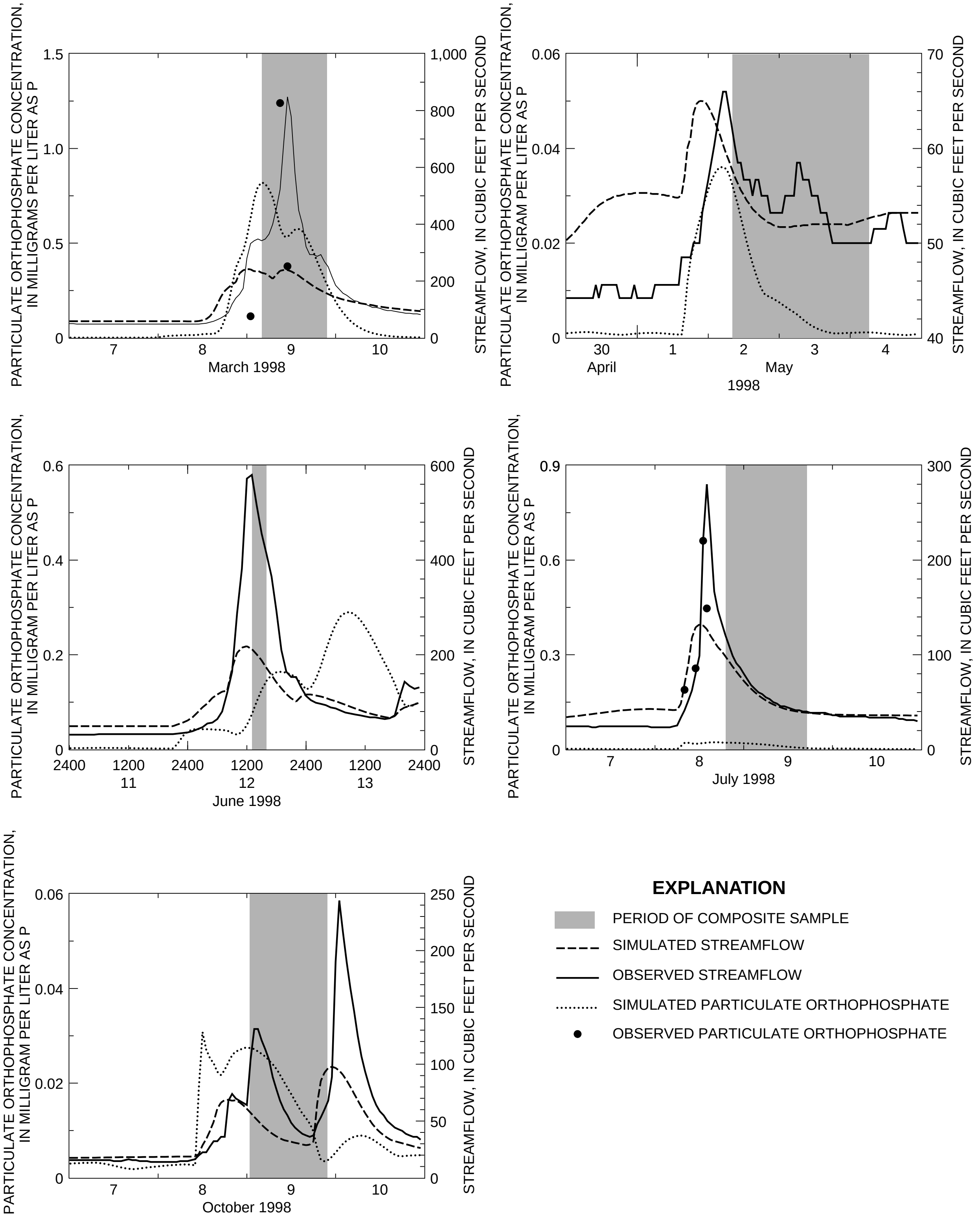

Figure 35. Simulated and observed streamflow and particulate orthophosphate concentrations and period of composite sample during five storms in 1998 at streamflow-measurement station 01480000, Red Clay Creek at Wooddale, Del.

Data from composite stormflow samples collected in 1998 were used in the calculation of dissolved orthophosphate and particulate orthophosphate loads. Calculated loads served as the observed values in the evaluation of overall phosphorus transport during storms. Simulated and observed streamflow, and dissolved and particulate orthophosphate loads for storm events in 1998 are presented in table 25. Observed loads of particulate orthophosphate commonly are greater than observed loads of dissolved orthophosphate. For one small storm in May 1998, dissolved orthophosphate loads were greater than particulate orthophosphate loads. Dissolved and particulate orthophosphate loads tend to be undersimulated when flow is undersimulated, with the exception of the March 1998 storm.

The difference between observed and simulated dissolved orthophosphate loads ranged from -77 to 98 percent for individual storms and was -32 percent for the total of all storms (table 25). The difference between observed and simulated particulate orthophosphate loads ranged from -95 to 36 percent for individual storms and was -35 percent for the total of all storms. At the monitoring site at Wooddale on Red Clay Creek, some errors may be associated with estimated contributions of phosphorus from point sources in addition to those associated with simulated orthophosphate from nonpoint sources. The greater undersimulation of particulate orthophosphate compared to dissolved orthophosphate may be related to errors in partitioning from dissolved to sorbed phases and to errors in sediment transport. As discussed in the sections on sediment and nitrogen, some error in load simulations is due to the error in streamflow simulation. Adjusting for the cumulative error of -24 percent for simulated streamflow, the cumulative errors of -32 and -35 percent for simulated dissolved and particulate orthophosphate loads at Wooddale (table 25) indicate cumulative errors of -10 and -14 percent associated with the simulation of dissolved and particulate orthophosphate concentrations for the five storms. Using monthly or yearly annual load criteria (Donigian and others, 1984), the dissolved and particulate orthophosphate calibration is “worse than fair” for individual storm loads but “good” for the cumulative storms loads.

Simulated concentrations of dissolved orthophosphate under base-flow conditions were less than observed concentrations at the Red Clay Creek at Wooddale monitoring site in 1998 (fig. 36). The mean difference between observed and simulated dissolved orthophosphate for base-flow conditions was 0.109 mg/L as P, and the average percent difference was about -60 percent. As noted previously, streamflow was well simulated for all base-flow samples (fig. 19). Simulated concentrations of particulate orthophosphate under base-flow conditions were both lower and higher than observed concentrations. The mean difference between observed and simulated particulate orthophosphate for three samples collected under base-flow conditions was 0.04 mg/L as P, and the average percent difference was -11 percent.

Data collected by PADEP and DNREC at three streamflow-measurement stations under a range of hydrologic conditions also were used to evaluate the simulation of dissolved orthophosphate. All three of the sites are downstream of

Table 25. *Simulated and observed streamflow and dissolved and particulate orthophosphate loads for storms sampled in 1998 at the nonpoint-source monitoring site, 01480000 Red Clay Creek at Wooddale, Del.*

[ft^3/s, cubic feet per second; na, not applicable; nd, not done]

Dates of storm sampling	Peak flow[1] (ft^3/s)	Streamflow volume (millions of cubic feet)			Dissolved orthophosphate load (pounds as phosphorus)			Particulate orthophosphate load (pounds as phosphorus)		
		Simulated	Observed	Percent difference[2]	Simulated	Observed	Percent difference[2]	Simulated	Observed	Percent difference[2]
March 8-9	688	14.68	19.33	-24	164	83	98	486	357	36
May 2-3	66	7.45	7.62	-2	27	72	-62	9	27	-67
June 12	580	3.05	7.38	-59	13	57	-77	13	270	-95
July 8-9	280	7.77	9.11	-15	24	90	-73	10	143	-93
October 8-9	74	4.20	5.68	-26	15	56	-73	na	nd	na
Total (all storms)		37.15	49.12	-24	243	358	-32	518	797	-35

[1] Peak mean hourly discharge during period of composite sampling.

[2] 100 x (observed-simulated)/observed.

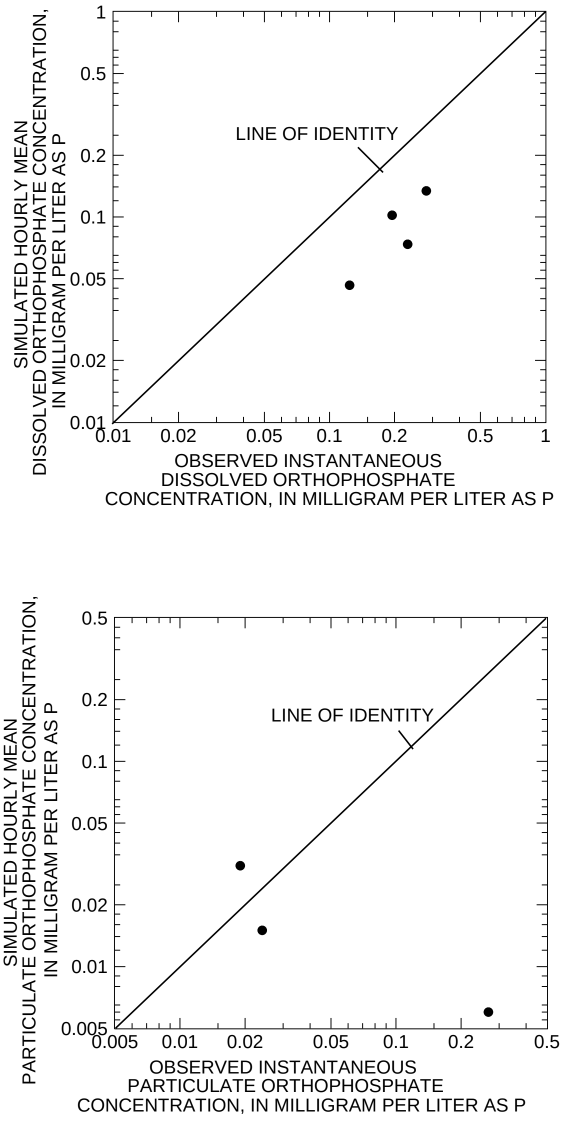

Figure 36. Simulated hourly mean and observed instantaneous dissolved and particulate orthophosphate concentrations during base-flow conditions in 1998 at streamflow-measurement station 01480000 Red Clay Creek at Wooddale, Del.

point-source discharges. As noted earlier, most of the samples were collected under moderate or base-flow conditions (fig. 20). Dissolved-orthophosphate concentrations frequently were slightly undersimulated (fig. 37). The average difference between simulated and observed dissolved-orthophosphate concentrations was -29 percent for Red Clay Creek near Kennett Square, -24 percent for Red Clay Creek at Wooddale, and -12 percent for Red Clay Creek near Stanton. At all sites, simulated orthophosphate loads generally were within a factor of 5 or less of observed loads (fig. 37). Errors in load estimates of dissolved orthophosphate from point sources and nonpoint sources as well as instream processes may contribute to overall errors of instream orthophosphate concentrations.

Overall, the dissolved and particulate orthophosphate simulation under base-flow and stormflow conditions generally appears to represent the observed patterns of phosphorus concentrations in response to flow conditions and defined land uses. At the nonpoint-source monitoring site, 01480000 Red Clay Creek at Wooddale, errors expressed in percent are greater for particulate orthophosphate simulation than for dissolved orthophosphate simulation under stormflow conditions. In most storms, observed particulate orthophosphate loads commonly are from 1.5 to 5 times greater than observed dissolved-orthophosphate loads (table 25).

Simulated annual yields of phosphorus varied by land use. Simulated yields of total orthophosphate (dissolved plus adsorbed or particulate orthophosphate) are presented per land-use category per segment per year in table 26 and mean yields of total orthophosphate for the simulation period are presented per land-use category per segment in table 27.

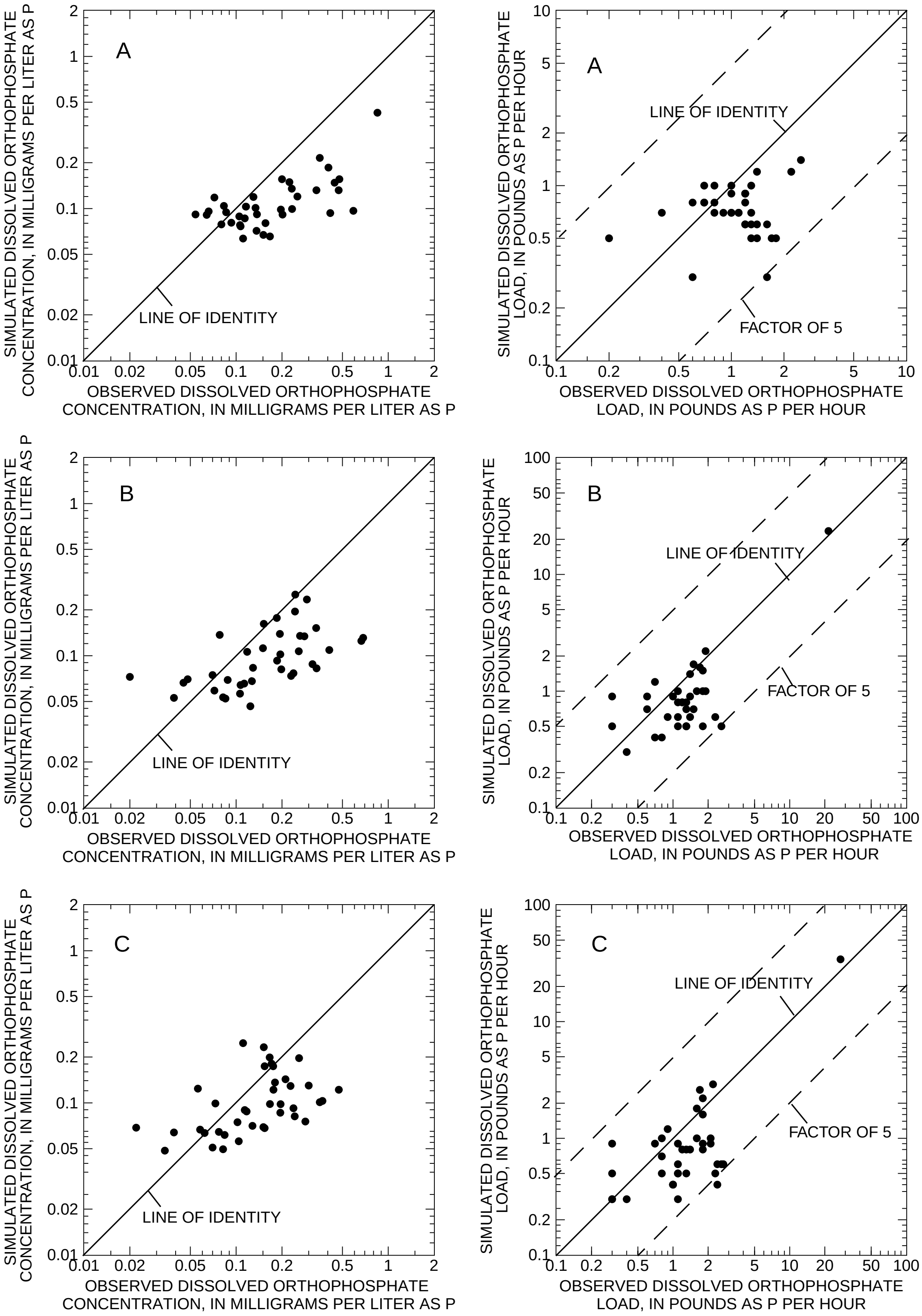

Figure 37. Simulated hourly mean and observed instantaneous dissolved orthophosphate concentrations and loads at streamflow-measurement stations (A) 01479820, Red Clay Creek near Kennett Square, Pa., (B) 01480000, Red Clay Creek at Wooddale, Del., and (C) 01480015, Red Clay Creek at Stanton, Del., October 1994 through October 1998. (Data from Pennsylvania Department of Environmental Protection and Delaware Department of Environmental Control.)

Table 26. *Observed annual precipitation and simulated annual total (dissolved plus adsorbed) orthophosphate yields by land use for the three segments of the Hydrological Simulation Program–Fortran (HSPF) model for Red Clay Creek Basin, 1995-97*

	Year				
	Segment	**1995**	**1996**	**1997**	**1995-97 average**
Precipitation (inches)[1]	7,4,6	40.59	61.98	35.01	45.86
Simulated annual total orthophosphate yield (pounds as phosphorus per acre per year), by land-use category[2]					
Residential - unsewered	7	.136	.501	.131	.256
Residential - sewered	7	.172	.504	.147	.274
Urban	7	.281	.479	.177	.312
Agricultural - animal/crop	7	7.17	13.1	5.04	8.44
Agricultural - row crop	7	7.02	13.0	4.79	8.27
Agricultural - mushroom	7	28.3	55.8	13.3	32.5
Forested	7	.010	.031	.019	.020
Open	7	.166	.565	.127	.286
Wetlands/water	7	.006	.020	.012	.013
Undesignated	7	.158	.566	.126	.283
Impervious - residential	7	.407	.397	.401	.402
Impervious - urban	7	.932	.868	.918	.906
Simulated annual total orthophosphate yield (pounds as phosphorus per acre per year), by land-use category[2]					
Residential - unsewered	4	.125	.463	.114	.234
Residential - sewered	4	.151	.482	.123	.252
Urban	4	.254	.465	.153	.291
Agricultural - animal/crop	4	5.86	13.0	3.90	7.59
Agricultural - row crop	4	5.63	12.9	3.57	7.37
Agricultural - mushroom	4	26.3	54.5	11.9	3.90
Forested	4	.100	.030	.017	.049
Open	4	.120	.514	.090	.241
Wetlands/water	4	.006	.021	.012	.013
Undesignated	4	.116	.502	.085	.234
Impervious - residential	4	.405	.395	.400	.400
Impervious - urban	4	.929	.865	.915	.903
Simulated annual total orthophosphate yield (pounds as phosphorus per acre per year), by land-use category[2]					
Residential - unsewered	6	.105	.343	.084	.177
Residential - sewered	6	.130	.455	.098	.228
Urban	6	.191	.487	.134	.271
Agricultural - animal/crop	6	4.03	12.1	3.32	6.48
Agricultural - row crop	6	3.86	11.9	3.09	6.28
Agricultural - mushroom	6	13.7	5.50	6.45	23.6
Forested	6	.012	.033	.012	.019
Open	6	.114	.422	.083	.206
Wetlands/water	6	.008	.024	.008	.013
Undesignated	6	.113	.420	.082	.205
Impervious - residential	6	.403	.395	.399	.399
Impervious - urban	6	.925	.865	.913	.901

[1] Precipitation input to segment 7 = 0.85 × precipitation recorded at Coatesville.

[2] In pervious areas, unless noted.

Table 27. *Observed annual precipitation and simulated mean annual total orthophosphate yield by land use for pervious and impervious land areas in the three segments of the Hydrological Simulation Program–Fortran (HSPF) model for Red Clay Creek Basin, 1995-97*

	1995-97 Average			
	Segment 7	**Segment 4**	**Segment 6**	**Mean of all segments**
Precipitation (inches)	[1]45.86	45.86	45.86	45.86
Simulated mean annual total orthophosphate yield (tons per acre per year), by land-use category[2]				
Residential - unsewered	.256	.234	.177	.222
Residential - sewered	.274	.252	.228	.251
Urban	.312	.291	.271	.291
Agricultural - animals / crops	8.44	7.59	6.48	7.50
Agricultural - row crop	8.27	7.37	6.28	7.31
Agricultural - mushroom	32.5	3.90	23.6	29.0
Forested	.020	.049	.019	.029
Open	.286	.241	.206	.245
Wetlands / water	.013	.013	.013	.013
Undesignated	.283	.234	.205	.241
Impervious - residential	.402	.400	.399	.400
Impervious - urban	.906	.903	.901	.903

[1] Precipitation input to segment 7 = 0.85 × precipitation recorded at Coatesville.

[2] In pervious areas, unless noted.

Sensitivity Analysis

Calibration of water temperature is specified by 13 parameters; 5 for pervious land surfaces, 2 for impervious land surfaces, and 6 for stream reaches. For water-temperature simulation, the model is more sensitive to parameters in the reach modules than to parameters in pervious and impervious modules. Water temperature in a reach is simulated as a function of the variables: upstream flow and land-surface inflow temperatures; air temperature; and radiation, conduction, and convection gains or losses. Of these variables, radiation, conduction, and convection gains and losses have calibration parameters. Simulated water temperatures are most sensitive to the parameters CFSAEX, the solar radiation correction factor, and KCOND, the conduction-convection coefficient. Daily high temperatures are affected by CFSAEX and nighttime low temperatures by KCOND. In combination, CFSAEX and KCOND also affect daily mean water temperature.

The simulated sediment yield from pervious and impervious land areas is dependent on parameters affecting soil detachment, soil scour, and soil or sediment washoff and is sensitive to parameters affecting soil detachment (KRER, JRER), soil washoff (KSER, JSER), and soil-scour processes (KGER, JGER) for pervious land surfaces, and solids build up (ACCSDP, REMDSP) and washoff processes for impervious land surfaces (KEIM, JEIM). Sediment washoff or transport capacity is dependent on surface runoff (SURO) and, therefore, the hydrologic component of the simulation. In addition, calibration of suspended sediment in the stream channel is sensitive to parameters controlling shear stress regimes (TAUD, TAUS) that determine deposition on and scour of the channel bottom. The sensitivity of sediment yields to changes in parameters affecting pervious land-surface processes was investigated by varying para-meters by selected multiplication factors. Results reported at Red Clay Creek near Stanton, Del., include the total effects in the three segments above the station (table 28). Because nutrients can

Table 28. *Sensitivity of model output for sediment and nutrient yields at streamflow-measurement station 01480015 Red Clay Creek near Stanton, Del., to changes in selected parameters affecting sediment contributions from pervious land areas*

[Model parameters: KRER, coefficient in soil detachment equation; JRER, exponent in soil detachment equation; KSER, coefficient in detached-sediment washoff equation; JSER, exponent in detached-sediment washoff equation; KGER, coefficient in soil-matrix scour equation; JGER, exponent in soil-matrix scour equation]

Parameter	Multiplier	Sediment yield		Nitrate yield		Ammonia yield		Phosphorus yield	
		Tons per acre	Percent difference[1]	Pounds per acre	Percent difference	Pounds per acre	Percent difference	Pounds per acre	Percent difference
Preliminary calibration value[2]	1	3.34	0	47.01	0	1.89	0	18.04	0
				Detachment processes					
KRER	.5	1.93	-42.4	44.61	-5.1	1.19	-36.7	10.10	-44.0
KRER	2	4.71	41.0	49.39	5.1	2.67	41.4	26.73	48.2
JRER	.5	5.15	54.1	50.15	6.7	2.94	55.7	29.64	64.3
JRER	1.5	2.02	-39.5	44.78	-4.8	1.23	-34.7	10.56	-41.4
				Washoff processes					
KSER	.5	2.40	-28.1	45.46	-3.3	1.51	-20.1	13.56	-24.8
KSER	2	3.70	10.6	47.57	1.2	2.01	6.5	19.40	7.6
JSER	.75	3.78	13.1	47.67	1.4	2.04	8.2	19.81	9.8
JSER	1.5	2.02	-39.7	44.82	-4.7	1.30	-31.1	11.30	-37.3
				Soil-scour processes					
KGER	.5	3.30	-1.2	47.01	0	1.89	0	18.04	0
KGER	2	3.42	2.2	47.01	0	1.89	0	18.04	0
JGER	.5	3.55	6.2	47.01	0	1.89	0	18.04	0
JGER	1.5	3.42	2.2	47.01	0	1.89	0	18.04	0

[1] Percent difference from calibrated value = 100 x (changed result - calibrated result)/calibrated result.

[2] All parameters.

be attached to sediment, factors affecting sediment yields also affect nutrient yields. The sensitivity of nutrient yields to changes in parameters that control sediment yields from land surfaces is shown in table 28. Ammonia and phosphorus yields are more sensitive than nitrate yields to changes in sediment parameters.

The simulated yields of nitrate, ammonia, and phosphate from pervious and impervious land areas are dependent on parameters affecting concentrations of each constituent on sediment (POTFW) and in interflow (IFLW-CONC) and ground water (GRND-CONC). The sensitivity of simulated total nutrient yields to changes in these parameters was investigated by varying the parameters by selected multiplication factors (table 29). The parameters affecting ground-water concentrations affect nitrate yields more than yields of ammonia and phosphorus because of differences in the primary mechanisms that deliver these nutrients to the streams. Consequently, changes to parameters affecting concentrations of nutrients in soil (POTFW) and interflow (IFLW-CONC) affect yields of ammonia and phosphorus more than nitrate.

Model Limitations

The simulation of water-quality constituent concentrations and loads is dependent on the output of the hydrologic portion of the model. Thus, the accuracy of the water-quality simulations will be limited by the hydrologic model. In addition, the water-quality calibration was based on few (six or less storms) observed water-quality data; therefore, compared to a calibration with many water-quality data, greater uncertainty is associated with the simulation of water quality and assessment of the model performance is more difficult.

Model parameters used for water-quality simulation were obtained from calibration of models in adjacent basins of various sizes and may not be representative of land uses in the Red Clay Creek Basin. Concentrations of suspended sediment, nitrate, ammonia, and phosphorus for individual storms or short time periods may not be well simulated by the model because of hydrologic limitations related to accuracy of rainfall data. The timing and intensity of rainfall affect detachment processes for soil and soil-related constituents, as well as transport of the solids from land to streams. Simulated sediment concentrations were calibrated using measured suspended-solids concentrations in samples collected at one point in the stream. However, these point samples may not accurately represent average suspended-sediment concentrations for the entire cross section in stream reaches that are not well mixed. Simulation of water quality may be less accurate for small-basin

Table 29. *Sensitivity of model output for total nutrient yields at streamflow-measurement station 01480015 Red Clay Creek near Stanton, Del., to changes in selected model parameters affecting nutrient contributions from pervious land areas*

[Model parameters: POTFW, potency factor of sediment in washoff; IFLW-CONC, concentration in interflow; GRND-CONC, concentration in ground water]

Parameter	Multiplier	Nitrate as N		Ammonia as N		Phosphate as P	
		Pounds per acre	Percent difference[1]	Pounds per acre	Percent difference	Pounds per acre	Percent difference
Preliminary calibration value[2]	1	47.01	0	1.89	0	18.04	0
POTFW	0.5	44.26	-5.9	1.11	-40.9	9.21	-49.0
POTFW	2	52.48	11.6	3.43	81.7	35.70	97.9
IFLW-CONC	0.5	43.52	-7.4	1.85	-1.7	18.00	-.2
IFLW-CONC	2	53.63	14.1	1.95	3.4	18.11	.4
GRND-CONC	0.5	29.54	-37.2	1.74	-7.5	17.89	-.8
GRND-CONC	2	81.96	74.3	2.17	14.9	18.34	1.7

[1] Percent difference from calibrated value = 100 x (changed result - calibrated result)/calibrated result.

[2] All parameters.

areas than for large-basin areas because of model spatial resolution. The hydrologic component of the model was calibrated at sites on the main branches and main stem of the Red Clay Creek rather than at small-basin sites.

The simulation of the nutrients, nitrogen and phosphorus, included the biological processes of algal plankton and benthic algal nutrient uptake and release but not the effect of zooplankton. Thus, the magnitude of diurnal fluctuations in concentrations of dissolved oxygen due to processes of instream photosynthesis and respiration may not be fully characterized by the simulation. The simulation of instream nutrient concentrations is affected further by the quality and quantity of information about nutrients in discharge from point sources. For example, although the model is run on an hourly time step, data on point-source discharges generally are available as monthly mean values for ammonia and contributions of phosphorus. Nitrate discharges are extrapolated from reported monthly ammonia concentrations in discharges. The model, as configured, is better used to estimate loads of nonpoint-source nutrients from land areas than to predict concentrations after considerable instream transport and residence time at downstream sites.

The simulation of particulate orthophosphorus was calibrated to an estimated value, calculated as observed total-phosphorus concentration minus observed dissolved-phosphorus concentration. This difference, however, may include forms of phosphorus other than orthophosphorus. Because the model, as configured, only simulates orthophosphorus, particulate phosphorus that includes other forms of phosphorus may be undersimulated.

MODEL APPLICATIONS

The HSPF model for the Red Clay Creek Basin was developed to assist in the assessment of suspended sediment and nutrient loads from nonpoint sources to streams. The model-simulated load estimates may be used as part of an ongoing TMDL assessment for the Christina River Basin to indicate the possible location and magnitude of load reductions that might be needed to maintain or improve water quality where impaired. These load estimates are based on the land-use conditions during the period of calibration and do not reflect the effects of best- management practices put in place after 1998 (Daniel Greig, Chester County Conservation District, oral commun., 2002).

The model can be used to estimate loads from individual basins for the purposes of evaluating relative and absolute contributions of suspended sediment, nitrogen, and phosphorus. This information may be helpful in assessing areas that appear to generate elevated nonpoint-source loads of these constituents. For example, simulated total loads and loads per acre in 1995 for selected headwater areas are listed in table 30. Precipitation in 1995 was similar to the long-term average, and yields in that year might be assumed to be similar to average. Results of model simulation indicate that for this time period, nitrate loads per acre are lower in the Burroughs Run subbasin than in the upper East and West Branches of Red Clay Creek. Land use in the Burroughs Run subbasin is relatively more residential and less agricultural than in the other two subbasins (table 9).

The HSPF model for the Red Clay Creek Basin can be used to compare simulated loads in the Red Clay Creek and adjacent basins, where monitoring data are limited, to loads calculated

Table 30. *Simulated total loads and loads per acre in 1995 for selected headwater model-reach drainage areas in the Hydrological Simulation Program–Fortran (HSPF) model of the Red Clay Creek Basin, Pennsylvania and Delaware (See figure 11 for location of model reaches.)*

[lb, pounds; lb/acre, pounds per acre; tons/acre, tons per acre]

Model reach number	Model-reach stream name	Drainage area (acres)	Relative loads (mass per acre)				Total loads (mass)			
			Nitrate (lb/acre)	Ammonia (lb/acre)	Phosphate (lb/acre)	Sediment (tons/acre)	Nitrate (lb)	Ammonia (lb)	Phosphate (lb)	Sediment (tons)
1	Upper W. Br. Red Clay Creek	6,451	9.14	0.55	5.55	1.07	58,940	3,538	35,800	6,920
3	Upper E. Br. Red Clay Creek	6,336	8.14	.71	6.58	.90	53,270	4,471	41,710	5,697
6	Burroughs Run[1]	4,554	5.78	.17	2.51	.64	26,280	755	11,390	2,902

[1] Loads for Burroughs Run include contributions from a small point-source discharge.

from extensive observed data in nearby basins to the west that drain to the Chesapeake Bay. Evaluation of monitoring data from these nearby basins indicates a positive correlation between the percentage of land in agricultural use and calculated yields of nitrate, ammonia, phosphorus, and suspended sediment (Langland and others, 1995). Similar relations are indicated by results of the HSPF model for the Brandywine Creek, White Clay Creek, and Red Clay Creek (Senior and Koerkle, 2003a, 2003b). Comparison of simulated and calculated yields indicates that the simulation provides reasonable results (figs. 38 and 39).

The HSPF model for the Red Clay Creek Basin also can be used to compare simulated loads from nonpoint sources based in land areas to reported loads from point-source discharges to streams in the basin. For example, total nitrate, ammonia, and orthophosphorus loads as estimated by the HSPF model for the drainage area above Red Clay Creek near Stanton, Del., are listed with estimated and reported loads from point-source discharges to the Brandywine in table 31. Simulated loads for ammonia from nonpoint sources are about equal to the estimated loads for ammonia from point sources. Simulated nitrate loads are about 25 times greater than estimated nitrate loads from point sources, and simulated phosphorus loads from nonpoint sources are about 20 times greater than estimated phosphorus loads from point sources.

The simulated loads shown in table 31 are for the whole basin for the 4-year period (October 1994-October 1998) and include a range of hydrologic conditions. Model-simulated loads from the whole basin and selected subbasins in the Red Clay Creek Basin could be estimated under base-flow or stormflow conditions for an actual time period, such as 1996-97. Additionally, the HSPF model for the Red Clay Creek Basin may be used as a predictive tool to estimate loads under statistically identified flow conditions, such as based on some period of record. For example, the model could be used to estimate an average daily phosphorus load at high-flow conditions for daily mean flows that occur between about 5 and 10 percent of the time based on the simulation period. At streamflow-measurement station 01480015 Red Clay Creek near Stanton, model simulation indicates that average daily phosphorus loads from both nonpoint and point sources is 9.2 lbs at high-flow conditions for daily mean flows of 100 - 200 ft^3/s that occur between about 5 and 10 percent of the time based on the simulation period of 1994-98. Further, the model simulation indicates that about 80 percent of the total phosphorus load for the period 1994-98 at Red Clay Creek near Stanton is carried by daily mean flows of greater than 200 ft^3/s and that occur 5 percent or less of the time.

Table 31. *Total simulated nonpoint-source and estimated point-source loads of nitrate, ammonia, and phosphorus for the 4-year period October 1994 through September 1998, Red Clay Creek Basin*

	Total load, 1994-98[1], in tons		
	Nitrate[2]	Ammonia	Phosphorus
Nonpoint source[3]	695	29	[4] 266
Point source[5]	26	31	13

[1] Period from October 1, 1994, through September 30, 1998.

[2] Estimated from reported ammonia loads.

[3] Calculated for drainage area above the station Red Clay Creek near Stanton, Del.

[4] Nonpoint source estimates are total orthophosphate.

[5] Includes all discharges above Stanton, Del.

Successful application of the Red Clay Creek HSPF model to future scenarios or periods of record other than the calibration period will be best supported if the model was calibrated to a broad range of representative hydrologic conditions. The Red Clay Creek model was calibrated to a range of streamflows conveying all but the most extreme high-flow and low-flow events. Comparison of the daily mean streamflow-duration curve for the simulation period at station 01480000 Red Clay Creek at Wooddale, Del., to the daily mean streamflow-duration curve for the 57.5-year period from April 15, 1943, to September 30, 2001 (fig. 40), shows generally good agreement. Below about 12 ft^3/s, the duration curves are substantially different. Thus, the performance of the model simulations at these low flows is unknown; however, the transport of suspended nonpoint-source constituents can be expected to be negligible during these infrequent flows. The highest streamflows generally produce the largest loads of suspended constituents, but they also are infrequent events. Daily mean streamflows greater than 1,600 ft^3/s only have been exceeded seven times in the 57.5-year period of record examined and once in the simulation period.

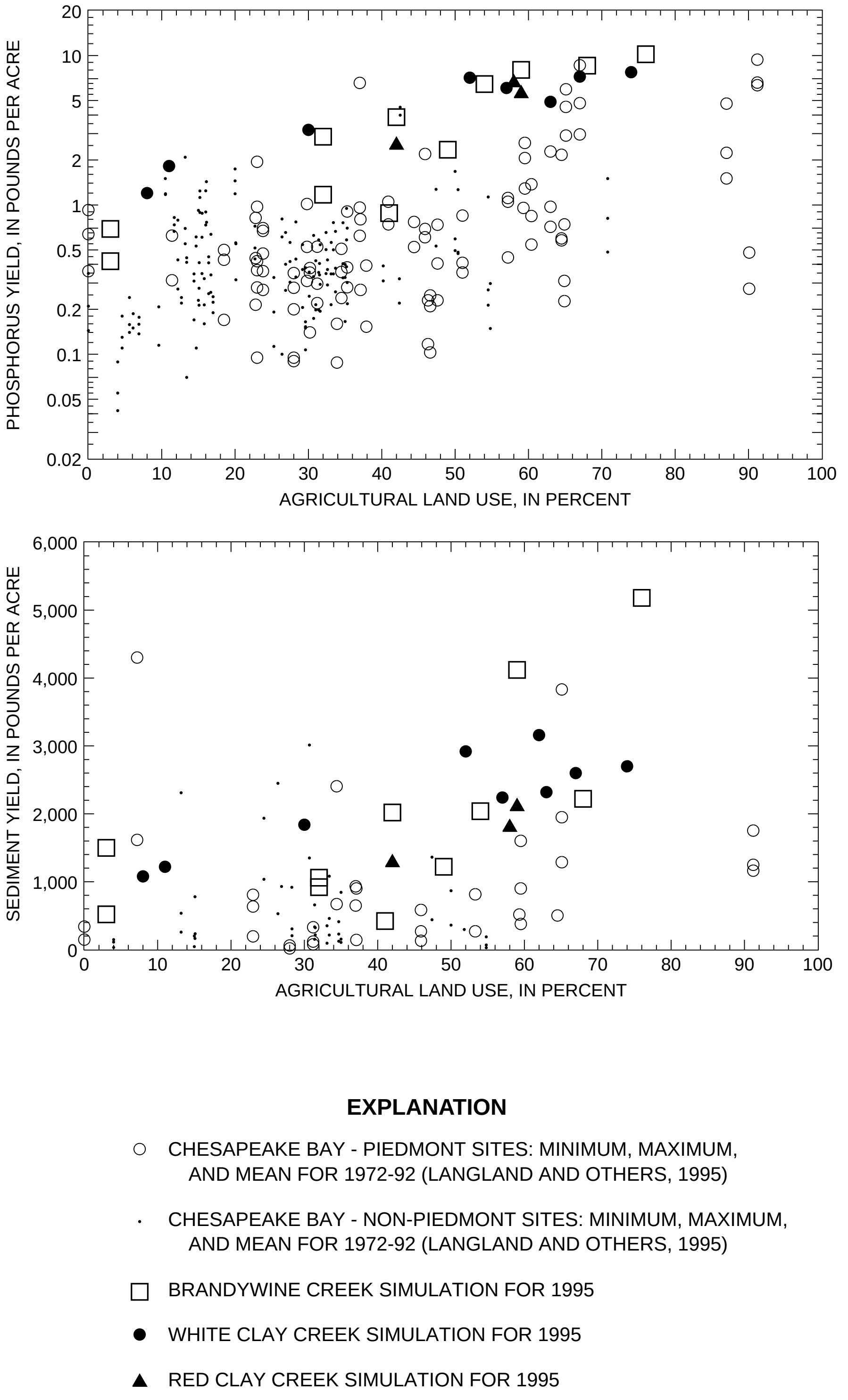

Figure 38. Sediment and phosphorus yields in relation to percent agricultural land use as calculated from observed data for subbasins in the Chesapeake Bay Watershed and as simulated by the Hydrological Simulation Program–Fortran (HSPF) model for selected subbasins in the Brandywine Creek, White Clay Creek, and Red Clay Creek Basins, Pennsylvania and Delaware.

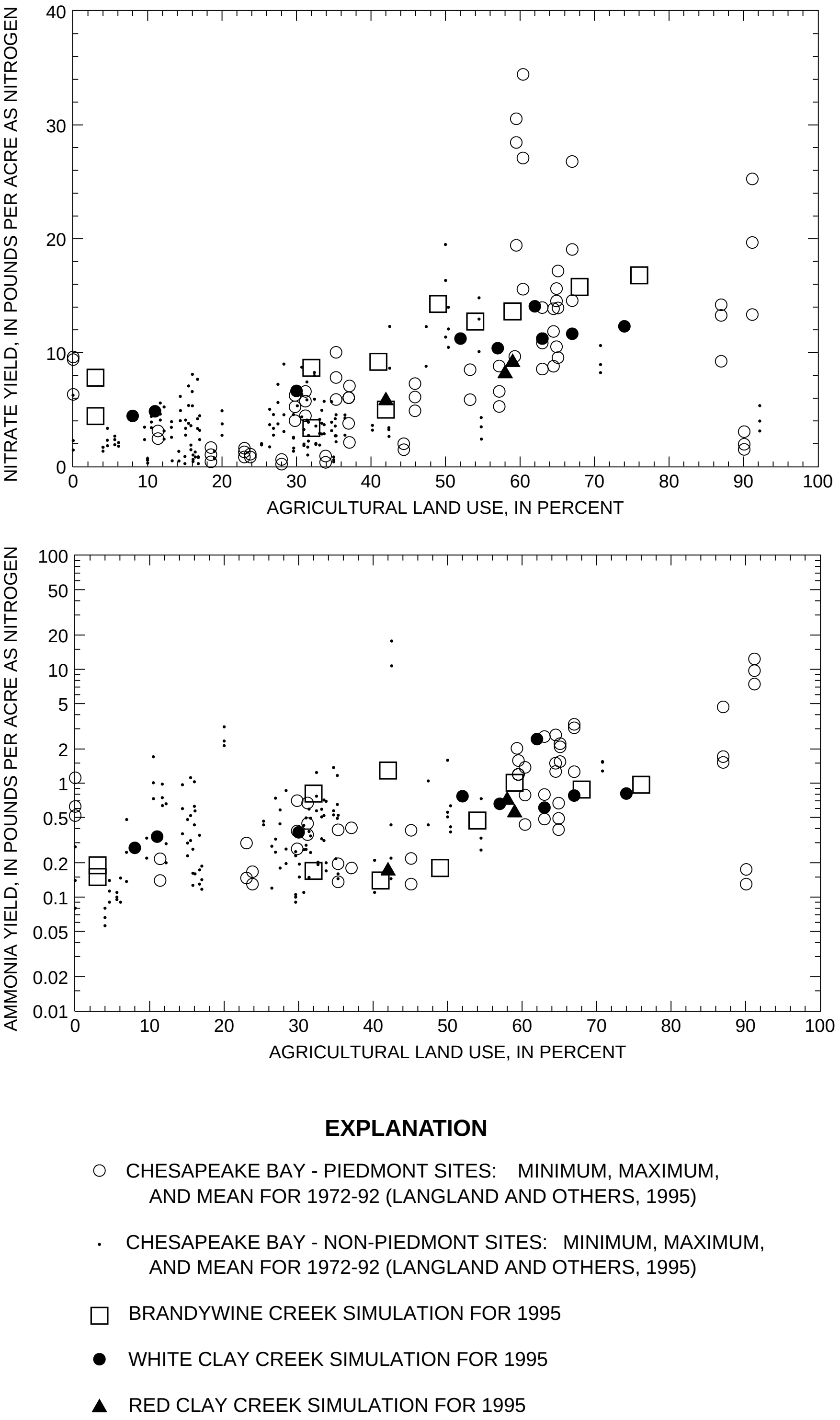

Figure 39. Yields of nitrate and ammonia in relation to percent agricultural land use as calculated from observed data for subbasins in the Chesapeake Bay Watershed and as simulated by the Hydrological Simulation Program–Fortran (HSPF) model for selected subbasins in the Brandywine Creek, White Clay Creek, and Red Clay Creek Basins, Pennsylvania and Delaware.

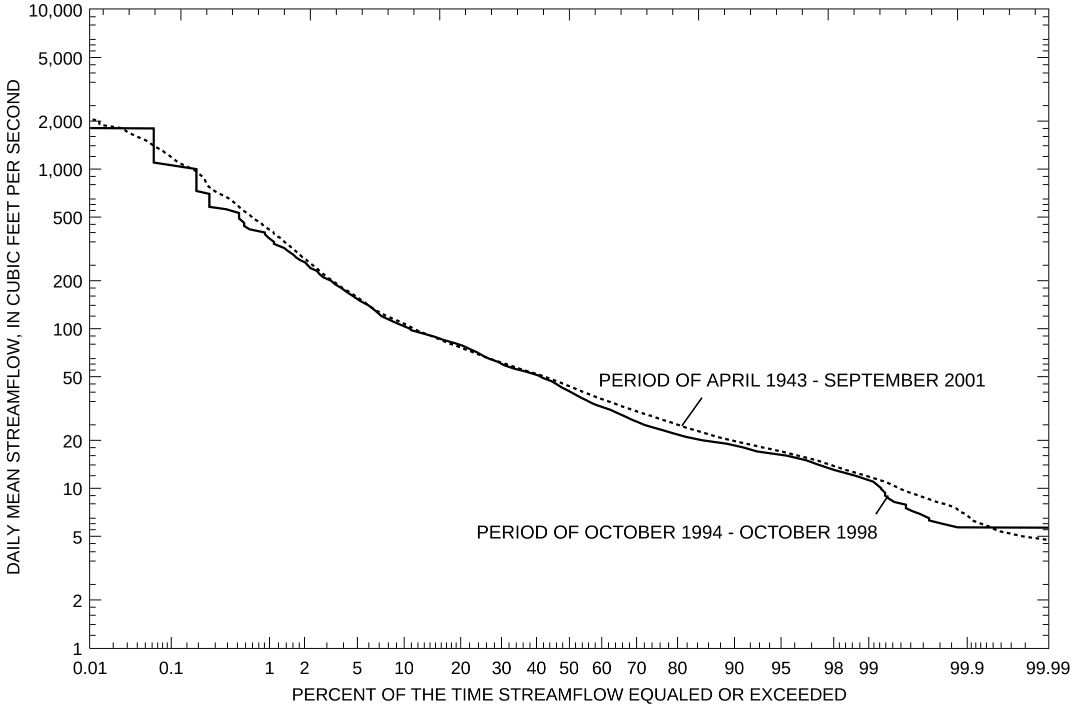

Figure 40. Duration curves of observed daily mean streamflow at 01480000 Red Clay Creek at Wooddale, Del., for the period April 1, 1943, through September 30, 2001, and for the period of simulation, October 1, 1994, through October 29, 1998.

SUMMARY

The Christina River Basin drains 565 mi^2 in Pennsylvania and Delaware and is used for recreation, drinking-water supply, and support of aquatic life. The Christina River Basin includes the major subbasins of Brandywine Creek, Red Clay Creek, White Clay Creek, and the Christina River. The Red Clay Creek is the smallest of the four main subbasins and drains an area of 54 mi^2. Monitoring data indicate that water quality in some parts of the Christina River Basin is impaired and does not support the States' designated uses of the stream. A water-quality management strategy developed by a group of local, county, State, and Federal agencies to address water-quality problems included a modeling component to evaluate the effects of point and nonpoint-source contributions of nutrients and suspended sediment on stream water quality. The model selected for the nonpoint-source evaluation was HSPF. The HSPF model for the Christina River Basin was constructed and calibrated by the USGS, in cooperation with the DRBC, DNREC, and PADEP, and consists of four independent models, one for each of the four main subbasins.

The USGS also developed and executed a monitoring plan to collect water-quality data in each of the four main subbasins and in small areas predominantly covered by one land-use category for model calibration. Under this monitoring plan, stormflow and base-flow samples were collected during 1998 at 1 site in the Red Clay Creek subbasin and 10 sites elsewhere in the Christina River Basin. Seven of the 11 total monitored stream sites in the Christina River Basin drained areas, ranging in size from 0.6 to 18.7 mi^2, that were covered predominantly by one land use: animal / row crop; agricultural; row-crop agricultural; forested; sewered residential; unsewered residential; or urban. The nonpoint-source monitoring site at the streamflow-measurement station, 01480000 Red Clay Creek at Wooddale, was about 4 mi upstream of the outlet of the Red Clay subbasin and drained 47 mi^2 of mixed land uses. Water samples were analyzed for dissolved and total nutrients and suspended solids. Because suspended-sediment analyses were not available, suspended-solids data were used as a surrogate for suspended-sediment data. Suspended solids and total phosphorus concentrations were higher in stormflow than in base-flow samples, whereas dissolved nitrate concentrations tended to be higher in base-flow than stormflow samples.

The HSPF model for the Red Clay Creek Basin was used to simulate streamflow, suspended sediment, and the nutrients of nitrogen and phosphorus. For the model, the basin was subdivided into nine reaches draining areas that ranged from 1.7 to 10.1 mi^2. One of the reaches contains a regulated reservoir. Ten different pervious land uses and two impervious land uses were selected for simulation. Land-use areas were determined from 1995 land-use data. The predominant land uses in the Red Clay Creek Basin are agricultural, forested, residential, and urban.

The hydrologic component of the HSPF model was run at an hourly time step and calibrated using streamflow data at three USGS streamflow-measurement stations for the period October 1, 1994, through October 29, 1998. Daily precipitation data from one NOAA gage near the Red Clay Creek Basin to the east and hourly precipitation-intensity data from one NOAA gage near the tip of the basin to the south were used for model input. The difference between observed and simulated streamflow volume ranged from -0.8 to 2.1 percent for the 4-year period at the three sites used for model calibration. Annual differences between observed and simulated streamflow generally were greater than the overall error. For example, near the outlet of the basin at streamflow-measurement station 01480015, Red Clay Creek near Stanton, Del. (drainage area of 50.2 mi^2), annual differences between observed and simulated streamflow ranged from -5.8 to 6.0 percent and the overall error for the 4-year period was -0.8 percent (-0.6 in.). At the three streamflow-measurement stations, calibration errors for total flow volume, low-flow-recession rate, 50-percent lowest flows, 10-percent highest flows, storm peaks and other seasonal measures generally were within recommended criteria for a satisfactory calibration. Much of the error in simulating storm events on an hourly time step can be attributed to uncertainty in the rainfall data.

Model parameters affecting water quality were taken, with minor adjustments, from calibrated HSPF models for the adjacent White Clay and Brandywine Creek Basins, where data were available to calibrate inputs from specific land uses. The calibration of the water-quality component of the Red Clay Creek model was assessed using monitoring data collected at three USGS streamflow-measurement stations with variable periods of record ending October 1998. All three stations were downstream of point-source discharges. The date for the start of water-quality monitoring ranged from October 1994 to January 1998. Suspended-solids data collected during monitoring were used as estimates for suspended sediment. Fewer data were available for water-quality calibration than for streamflow calibration. On the basis of limited water-quality data, simulated loads of suspended sediment, nitrate, dissolved and particulate ammonia, and dissolved orthophosphate and particulate phosphorus are within an order of magnitude or less of observed loads for storms sampled in 1998 at the nonpoint-source monitoring site, 01480000 Red Clay Creek at Wooddale, Del., and for grab samples collected by State agencies at the three streamflow-measurement stations. Errors in ammonia simulation apparently are greater than errors in nitrate and orthophosphate simulation. Some error could be related to variability in point-source discharges upstream of monitoring sites. The error in water-quality loads typically is larger than and includes the error in stormflow simulation. Cumulative errors for five storms in 1998 at the Wooddale monitoring site, adjusted for the error in streamflow simulation, were -26 percent for suspended-sediment loads, -22 percent for nitrate loads, 58 percent for dissolved ammonia loads, -45 percent for particulate ammonia loads, -10 percent for dissolved-orthophosphate loads, and -14 percent for particulate orthophosphate loads. Error in simulation of dissolved constituents commonly was less than the error in simulation of particulate constituents. In storms, particulate phosphorus loads generally are greater than dissolved orthophosphate loads, and nitrate loads are about one order of magnitude greater than dissolved ammonia loads and two orders of magnitude greater than particulate ammonia loads.

Simulated yields (loads per acre) for suspended sediment, nitrate, ammonia, and orthophosphate were greatest from agricultural land uses compared to other land uses. Simulated yields of suspended sediment, nitrate, and ammonia for subbasins in the Red Clay Creek Basin were similar to yields simulated for adjacent basins and to yields calculated from monitoring data for subbasins in the nearby Chesapeake Bay Watershed. Yields (expressed in pounds per acre) of these constituents tend to increase as the percent of agricultural land increases. Simulated loads of nitrate and orthophosphate from nonpoint sources were greater than estimated loads of nitrate and phosphorus from point sources. However, simulated loads of ammonia from nonpoint sources were less than estimated loads of ammonia from point sources.

Users of the Red Clay Creek HSPF model should be aware of model limitations and consider the following when predictive scenarios are desired: duration curves indicate that the model simulates streamflow reasonably well when evaluated over a broad range of conditions and time, although streamflow and the corresponding water quality for individual storm events may not be well simulated; streamflow-duration curves for the simulation period compare well with duration curves for the 57.5-year period ending in 2001 at Red Clay Creek at Wooddale, Del., and include all but the extreme high-flow and low-flow events; calibration for water quality was based on sparse data, with the result of increasing uncertainty in the water-quality simulation.

REFERENCES CITED

American Public Health Association, American Water Works Association, Water Environment Federation, 1995, Standard methods for the examination of water and wastewater (19th ed.): Washington, D.C., American Public Health Association.

Berg, T.M., Barnes, J.H., Sevon, W.D., Skema, V.W., Wilshusen, J.P., and Yannacci, D.S., 1989, Physiographic Provinces of Pennsylvania: Pennsylvania Geological Survey, Map 13, 1 sheet, scale 1:2,000,000.

Bicknell, B.R., Imhoff, J.C., Kittle, J.L., Jr., Donigian, A.S., Jr., and Johanson, R.C., 1997, Hydrological Simulation Program—Fortran, User's manual for version 11: Athens, Ga., U.S. Environmental Protection Agency, National Exposure Research Laboratory, EPA/600/R-97/080, 755 p.

DeGaetano, A.T., Eggleston, K.L., and Knapp, W.W., 1993, Daily solar radiation estimates for the Northeastern United States: Ithaca, N.Y., Northeast Regional Climate Center Research Series, Cornell University, Publication No. RR 93-4, 7 p.

_____1994, Daily evapotranspiration and soil moisture estimates for the Northeastern United States: Ithaca, N.Y., Northeast Regional Climate Center Research Series, Cornell University, Publication No. RR 94-1, 11 p.

Delaware State Climatologist, 2001, Monthly precipitation for Wilmington Porter Reservoir: accessed November 9, 2001, at *http://www.udel.edu/leathers/monthly.html*.

Donigian, A.S., Jr., and Davis, H.H., Jr., 1978, User’s manual for Agricultural Runoff Management (ARM) Model: Athens, Ga., U.S. Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratory, EPA-600/3-78-080.

Donigian, A.S., Jr., Imhoff, J.C., Bicknell, B.R., Kittle, J.L., Jr., 1984, Application guide for Hydrological Simulation Program - Fortran (HSPF): Athens, Ga., U.S. Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratory, EPA-600/3-84-065, 189 p.

REFERENCES CITED—Continued

_____1998, HSPFParm —An inter-active database of HSPF model parameters, version 1.0: Washington, D.C., U.S. Environmental Protection Agency, Exposure Assessment Branch, Standards and Applied Science Division, Office of Science and Technology.

Dunne, Thomas, and Leopold, L.B., 1978, Water in environmental planning: San Francisco, W.H. Freeman and Company, 817 p.

Durlin, R.R., 1995, Water resources data for Pennsylvania, Water Year 1994, Volume 1, Delaware River Basin: U.S. Geological Survey Water-Data Report PA-94-1, 312 p.

Durlin, R.R., and Schaffstall, W.P., 1997a, Water resources data for Pennsylvania, water year 1995, volume 1, Delaware River Basin: U.S. Geological Survey Water-Data Report PA-95-1, 375 p.

_____1997b, Water resources data for Pennsylvania, water year 1996, volume 1, Delaware River Basin: U.S. Geological Survey Water-Data Report PA-96-1, 367 p.

_____1998, Water resources data for Pennsylvania, water year 1997, volume 1, Delaware River Basin: U.S. Geological Survey Water-Data Report PA-97-1, 372 p.

_____1999, Water resources data for Pennsylvania, water year 1998, volume 1, Delaware River Basin: U.S. Geological Survey Water-Data Report PA-98-1, 405 p.

Flynn, K.M., Hummel, P.R., Lumb, A.M., and Kittle, J.L., Jr., 1995, User's manual for ANNIE, version 2, a computer program for interactive hydrologic data management: U.S. Geological Survey Water-Resources Investigations Report 95-4085, 211 p.

Fontaine, T.A., and Jacomino, V.M.F., 1997, Sensitivity analysis of simulated contaminated sediment transport: Journal of the American Water Resources Association, v. 33, no. 2, p. 313-326.

Gray, J.R., Glysson, G.D., Turcios, L.M., and Schwartz, G.E., 2000, Comparibility of suspended-sediment concentration and total suspended solids data: U.S. Geological Survey Water-Resources Investigations Report 00-4191, 14 p.

Greig., Dan, Bowers, Janet, and Kauffman, Gerald, eds., 1998, Final Phase I & II Report Christina River Basin Water Quality Management Strategy: West Chester, Pa., Chester County Conservation District and Chester County Water Resources Authority, and Newark, Del., Water Resources Agency for New Castle County, May 21, 1998.

James, L.D., and Burgess, S.J., 1982, Selection, calibration, and testing of hydrologic models *in* Haan, C.T., Johnson, H.P., and Brakensiek, D.L., eds., Hydrologic modeling of small watersheds: St. Joseph, Mich., American Soc. of Agricultural Engineers Monograph no. 5, p. 437-470.

James, R.W., Helinsky, B.M., and Simmons, R.H., 1996, Water resources data - Maryland and Delaware, water year 1995, volume 1. surface water data: U.S. Geological Survey Water-Data Report ME-DE-95-1, 382 p.

James, R.W., Helinsky, B.M., Simmons, R.H., and Tallman, A.J., 1997, Water resources data - Maryland and Delaware, water year 1996, volume 1. surface water data: U.S. Geological Survey Water-Data Report ME-DE-96-1, 352 p.

James, R.W., Helinsky, B.M., and Tallman, A.J., 1998, Water resources data - Maryland and Delaware, water year 1997, volume 1. surface water data: U.S. Geological Survey Water-Data Report ME-DE-97-1, 369 p.

James, R.W., Saffer, R.W., and Tallman, A.J., 1999, Water resources data - Maryland and Delaware, water year 1998, volume 1. surface water data: U.S. Geological Survey Water-Data Report ME-DE-98-1, 388 p.

Kittle, J.L., Jr., Lumb, A.M., Hummel, P.R., Duda, P.B., Gray, M.H., 1998, A tool for the generation and analysis of model simulation scenarios for watersheds (GenScn): U.S. Geological Survey Water-Resources Investigations Report 98-4134, 152 p.

Kunkle, W.M., 1963, Soil survey of Chester and Delaware Counties, Pennsylvania: U.S. Department of Agriculture Soil Conservation Service Soil Survey Series 1959, no. 19, 124 p.

REFERENCES CITED—Continued

Langland, M.J., Lietman, P.L., and Hoffman, S.A., 1995, Synthesis of nutrient and sediment data for watersheds within the Chesapeake Bay Drainage Basin: U.S. Geological Survey Water-Resources Investigations Report 95-4233, 121 p.

Lumb, A.M., Kittle, J.L., Jr., and Flynn, K.M., 1990, Users manual for ANNIE, a computer program for interactive hydrologic analyses and data management: U.S. Geological Survey Water-Resources Investigations Report 89-4080, 236 p.

Lumb, A.M., McCammon, R.B., and Kittle, J.L., Jr., 1994, Users manual for an expert system (HSPEXP) for calibration of the Hydrological Simulation Program–Fortran: U.S. Geological Survey Water-Resources Investigations Report 94-4168, 102 p.

Martin, G.R., Zarriello, P.J., and Shipp, A.A., 2000, Hydrologic and water-quality characterization and modeling of the Chenowith Run Basin, Jefferson County, Kentucky: U.S. Geological Survey Water-Resources Investigations Report 00-4239, 197 p.

Matthews, E.D., and Lavoie, O.L., 1970, Soil survey of New Castle County, Delaware: U.S. Department of Agricultural Soil Conservation Service in cooperation with Delaware Agricultural Experiment Station, 97 p.

Moore, C.R., 1987, Determination of benthic-invertebrate indices and water-quality trends of selected streams in Chester County, Pennsylvania, 1969-80: U.S. Geological Survey Water-Resources Investigations Report 85-4177, 62 p.

National Oceanic and Atmospheric Administration, 2000a, Monthly station normals of temperature, precipitation, and heating and cooling degree days, 1971-2000: Climatography of the United States no. 07, Delaware.

____2000b, Monthly station normals of temperature, precipitation, and heating and cooling degree days, 1971-2000: Climatography of the United States no. 36, Pennsylvania.

Pettyjohn, W.A., and Henning, Rodger, 1979, Preliminary estimation of ground-water recharge rates, related streamflow, and water quality in Ohio: Ohio State University Water Resources Center Project Completion Report 552, 323 p.

Reif, A.G., 1999, Physical, chemical, and biological data for selected streams in Chester County, Pennsylvania, 1981-94: U.S. Geological Survey Open-File Report 99-216, 607 p.

Rice, C.L., 1993, Environmental contaminants in soils and sediments from the Red Clay Creek Watershed, Pennsylvania and Delaware: U.S. Fish and Wildlife Service, Pennsylvania Field Office Special Project Report 93-7, 67 p.

Russell, M.A., Walling, D.E., and Hodgkinson, R.A., 2001, Suspended sediment sources in two small lowland agricultural catchments in the UK: Journal of Hydrology, v. 252, p. 1-24.

Senior, L.A., 1996, Ground-water quality and its relation to hydrogeology, land use, and surface-water quality in the Red Clay Creek Basin, Piedmont Physiographic Province, Pennsylvania and Delaware: U.S. Geological Survey Water-Resources Investigations Report 96-4288, 122 p.

Senior, L.A., and Koerkle, E.H., 2003a, Simulation of streamflow and water quality in the Brandywine Creek subbasin of the Christina River Basin, Pennsylvania and Delaware, 1994-98: U.S. Geological Survey Water-Resources Investigations Report 02-4279, 207 p.

____2003b, Simulation of streamflow and water quality in the White Clay Creek subbasin of the Christina River Basin, Pennsylvania and Delaware, 1994-98: U.S. Geological Survey Water-Resources Investigations Report 03-4031, 142 p.

____2003c, Simulation of streamflow and water quality in the Christina River subbasin and overview of simulations in other subbasins of the Christina River Basin, Pennsylvania, Maryland, and Delaware, 1994-98: U.S. Geological Survey Water-Resources Investigations Report 03-4193, 144 p.

REFERENCES CITED—Continued

Sloto, R.A., 1994, Geology, hydrology, and ground-water quality of Chester County, Pennsylvania: Chester County Water Resources Authority Water-Resource Report 2, 127 p.

Sloto, R.A., and Crouse, M.Y., 1996, HYSEP—A computer program for hydrograph separation and analysis: U.S. Geological Survey Water-Resources Investigations Report 96-4040, 46 p.

U.S. Environmental Protection Agency, 1999, WDMUtil Version 1.0(BETA) A tool for managing watershed modeling time-series data user's manual (DRAFT): EPA-823-C-99-001, 120 p.

____Region 3, 2000a, Hydrodynamic and water quality model of Christina River Basin, Final Report April 14, 2000.

____Office of Water, 2000b, EPA BASINS Technical Note 6 Estimating hydrology and hydraulic parameters for HSPF: EPA-823-R00-012, 32 p.

U.S. Geological Survey, 2000, Collection and use of total suspended solids data: U.S. Geological Survey Office of Surface Water and Office of Water Quality Technical Memorandum no. 2001.03.

Vogel, K.L., and Reif, A.G., 1993, Geohydrology and simulation of ground-water flow in the Red Clay Creek Basin, Chester County, Pennsylvania, and New Castle County, Delaware: U.S. Geological Survey Water-Resources Investigation Report 93-4055, 111 p.

Winter, T.C., 1981, Uncertainties in estimating the water balance of lakes: Water Resources Bulletin, American Water Resources Association, v. 17, no. 1, p. 82-115.

Zarriello, P.J., 1999, A precipitation-runoff model for part of the Ninemile Creek watershed near Camillus, Onandaga County, New York: U.S. Geological Survey Water-Resources Investigation Report 98-4201, 60 p.

APPENDIX 1

RESULTS OF LABORATORY ANALYSES OF STORMFLOW AND BASE-FLOW SAMPLES

***Table 1.** Results of laboratory analyses of discrete and composite samples collected during storms in 1998 at one nonpoint-source monitoring site in the Red Clay Creek basin, Pennsylvania and Delaware*

01480000 RED CLAY CREEK AT WOODDALE, DE (LAT 39 45 46N LONG 075 38 11W)

DATE	TIME	ENDING DATE	ENDING TIME	AGENCY ANALYZING SAMPLE (CODE NUMBER) (00028)	AGENCY COLLECTING SAMPLE (CODE NUMBER) (00027)	ELEV. OF LAND SURFACE DATUM (FT. ABOVE NGVD) (72000)	DISCHARGE, IN CUBIC FEET PER SECOND (00060)	DISCHARGE, INST. CUBIC FEET PER SECOND (00061)	DRAINAGE AREA (SQ. MI.) (81024)	SPECIFIC CONDUCTANCE LAB (US/CM) (90095)	CHLORIDE, DISSOLVED (MG/L AS CL) (00940)	RESIDUE TOTAL AT 105 DEG. C, SUSPENDED (MG/L) (00530)	NITROGEN, AMMONIA DISSOLVED (MG/L AS N) (00608)
MAR 1998													
08...	1630	19980309	1115	10003	1028	81.46	293	--	47.00	238	21.0	125	.089
09...	0215	--	--	10003	1028	81.46	--	337	47.00	264	21.7	85	.043
09...	1015	--	--	10003	1028	81.46	--	565	47.00	175	14.2	689	.119
09...	1215	--	--	10003	1028	81.46	--	839	47.00	196	15.2	249	.108
MAY													
01...	2251	19980503	1010	10003	1028	81.46	63	--	47.00	305	27.4	1	.028
JUN													
12...	1233	19980612	1515	10003	1028	81.46	578	--	47.00	251	22.6	317	.040
JUL													
08...	0940	--	--	10003	1028	81.46	--	49	47.00	261	20.2	59	.020
08...	0940	19980709	0804	10003	1028	81.46	114	--	47.00	268	22.0	82	.063
08...	1240	--	--	10003	1028	81.46	--	90	47.00	286	22.9	90	.007
08...	1410	--	--	10003	1028	81.46	--	280	47.00	298	25.3	275	.033
08...	1540	--	--	10003	1028	81.46	--	246	47.00	282	22.7	185	.054
OCT													
08...	1218	19981009	1009	10003	1028	81.46	71	--	47.00	328	35.0	29	<.005
09...	1218	--	--	10003	1028	81.46	--	22	47.00	363	33.0	20	.022
09...	1424	--	--	10003	1028	81.46	--	23	47.00	285	29.0	8	.059
09...	1554	--	--	10003	1028	81.46	--	32	47.00	282	29.0	12	.034
09...	1724	--	--	10003	1028	81.46	--	35	47.00	302	32.0	13	.032

01480000 RED CLAY CREEK AT WOODDALE, DE (LAT 39 45 46N LONG 075 38 11W)

DATE	NITROGEN,AMMONIA + ORGANIC DIS. (MG/L AS N) (00623)	NITROGEN,AMMONIA + ORGANIC TOTAL (MG/L AS N) (00625)	NITROGEN, AMMONIA TOTAL (MG/L AS N) (00610)	NITROGEN, NO2+NO3 DISSOLVED (MG/L AS N) (00631)	PHOSPHORUS DISSOLVED (MG/L AS P) (00666)	PHOSPHORUS ORTHO, DISSOLVED (MG/L AS P) (00671)	PHOSPHORUS TOTAL (MG/L AS P) (00665)	CARBON, ORGANIC DISSOLVED (MG/L AS C) (00681)	CARBON, ORGANIC TOTAL (MG/L AS C) (00680)	OXYGEN DEMAND, BIOCHEM CARBON. 20 (MG/L) (80087)	OXYGEN DEMAND, CHEMICAL (HIGH LEVEL) (MG/L) (00340)
MAR 1998											
08...	.85	2.2	.09	2.22	.097	.068	.389	7.0	7.0	5.2	23
09...	.74	1.8	.04	3.14	.185	.060	.299	7.0	5.0	6.2	7
09...	1.1	2.2	.16	1.35	.098	.073	1.34	8.0	8.0	10	61
09...	1.2	2.8	.13	1.68	.224	.186	.602	10	7.0	6.1	49
MAY											
01...	.82	.77	.05	3.38	.161	.149	.217	4.0	7.0	3.6	<1
JUN											
12...	.65	2.0	.05	2.75	.116	.122	.694	10	10	8.1	<1
JUL											
08...	.33	1.1	.03	2.27	.071	.105	.260	6.0	5.0	6.1	37
08...	.52	1.5	.07	2.36	.128	.157	.376	8.0	6.0	7.4	26
08...	.17	1.2	.03	2.69	.087	.117	.344	5.0	3.0	3.4	32
08...	.87	2.9	.04	2.75	.132	.147	.793	5.0	4.0	4.9	41
08...	.75	2.2	.05	2.73	.134	.154	.581	5.0	4.0	4.9	38
OCT											
08...	--	--	.05	3.22	--	.360	--	6.0	8.0	6.3	<1
09...	--	--	.04	2.96	--	.221	--	7.0	6.0	4.5	<1
09...	--	--	.05	2.69	--	.208	--	5.0	5.0	3.0	<1
09...	--	--	.06	2.78	--	.192	--	6.0	6.0	<3.0	<1
09...	--	--	.06	2.55	--	.205	--	6.0	6.0	<3.0	10

Remark codes used in this report:
< -- Less than

Table 2. *Results of laboratory analyses of grab samples collected during base-flow conditions in 1998 at one nonpoint-source monitoring site in the Red Clay Creek basin, Pennsylvania and Delaware*

DATE	TIME	AGENCY ANALYZING SAMPLE (CODE NUMBER) (00028)	AGENCY COLLECTING SAMPLE (CODE NUMBER) (00027)	ELEV. OF LAND SURFACE DATUM (FT. ABOVE NGVD) (72000)	DISCHARGE, INST. CUBIC FEET PER SECOND (00061)	DRAINAGE AREA (SQ. MI.) (81024)	OXYGEN, DISSOLVED (MG/L) (00300)	PH WATER WHOLE FIELD (STANDARD UNITS) (00400)	SPECIFIC CONDUCTANCE (US/CM) (00095)	TEMPERATURE WATER (DEG C) (00010)	ANC WATER UNFLTRD FET FIELD MG/L AS CACO3 (00410)	CHLORIDE, DISSOLVED (MG/L AS CL) (00940)	RESIDUE TOTAL AT 105 DEG. C, SUSPENDED (MG/L) (00530)
01480000 RED CLAY CREEK AT WOODDALE, DE (LAT 39 45 46N LONG 075 38 11W)													
JAN 1998													
12...	0956	10003	1028	81.46	26	47.00	13.2	7.2	349	.5	71	37.0	4
APR													
27...	1115	10003	1028	81.46	53	47.00	12.2	7.3	300	1.3	54	26.8	10
JUL													
23...	1226	10003	1028	81.46	24	47.00	9.5	7.9	328	24.4	73	34.0	5
SEP													
15...	1011	10003	1028	81.46	13	47.00	7.9	7.5	380	22.7	87	43.0	3

DATE	NITROGEN, AMMONIA DISSOLVED (MG/L AS N) (00608)	NITROGEN,AMMONIA + ORGANIC DIS. (MG/L AS N) (00623)	NITROGEN,AMMONIA + ORGANIC TOTAL (MG/L AS N) (00625)	NITROGEN, AMMONIA TOTAL (MG/L AS N) (00610)	NITROGEN, NO2+NO3 DISSOLVED (MG/L AS N) (00631)	PHOSPHORUS DISSOLVED (MG/L AS P) (00666)	PHOSPHORUS ORTHO, DISSOLVED (MG/L AS P) (00671)	PHOSPHORUS TOTAL (MG/L AS P) (00665)	CARBON, ORGANIC DISSOLVED (MG/L AS C) (00681)	CARBON, ORGANIC TOTAL (MG/L AS C) (00680)	OXYGEN DEMAND, BIOCHEM CARBON. 20 (MG/L) (80087)	OXYGEN DEMAND, CHEMICAL (HIGH LEVEL) (MG/L) (00340)	PHEOPHYTIN PHYTOPLANKTON, ACID M. (UG/L) (32218)
01480000 RED CLAY CREEK AT WOODDALE, DE (LAT 39 45 46N LONG 075 38 11W)													
JAN 1998													
12...	--	--	.72	.06	3.31	--	.195	.255	9.0	6.0	4.1	--	7.00
APR													
27...	.028	.71	1.2	.03	3.16	.135	.124	.154	4.0	4.0	<2.4	22	6.00
JUL													
23...	.020	.86	1.2	.03	2.64	.213	.230	.237	4.0	4.0	<2.4	2	2.00
SEP													
15...	<.005	.36	.65	<.01	3.18	.020	.281	.288	4.0	5.0	<2.4	6	4.00

DATE	CHLOROHPYLL A PHYTOPLANKTON ACID M. (UG/L) (32211)
01480000 RED CLAY CREEK AT WOODDALE, DE (LAT 39 45 46N LONG 075 38 11W)	
JAN 1998	
12...	3.00
APR	
27...	11.0
JUL	
23...	5.00
SEP	
15...	<1.00

Remark codes used in this report:
< -- Less than

APPENDIX 2

USER CONTROL INPUT FILE FOR RED CLAY CREEK HSPF MODEL

```
RUN
GLOBAL
RED CLAY CREEK HYDROLOGY - BASE SCENARIO - ALL SEGMENTS
  START       1994 10  1  0  0  END    1998 10 29 24  0
  RUN INTERP OUTPUT LEVEL    3    2
  RESUME     0 RUN     1                   UNIT SYSTEM     1
END GLOBAL

FILES
<type>  <fun>***<------------fname--------------------------------------------->
WDM        26   redclay.wdm
MESSU      25   redclay.ech
           90   REDCLAY.out
END FILES

OPN SEQUENCE
    INGRP              INDELT  1:00
      PERLND     702
      PERLND     703
      PERLND     704
      PERLND     705
      PERLND     706
      PERLND     707
      PERLND     708
      PERLND     709
      PERLND     710
      PERLND     711
      IMPLND     701
      IMPLND     702
      RCHRES       1
      RCHRES       3
      RCHRES       2
      GENER        1
      GENER        2
      COPY       10
      COPY       200
      PERLND     402
      PERLND     403
      PERLND     404
      PERLND     405
      PERLND     406
      PERLND     407
      PERLND     408
      PERLND     409
      PERLND     410
      PERLND     411
      IMPLND     401
      IMPLND     402
      RCHRES       4
      GENER        3
      GENER        4
      COPY       11
      RCHRES       6
      GENER        7
      GENER        8
    COPY     13
      RCHRES ***   7
      RCHRES       5
      GENER        5
      GENER        6
    COPY     12
      COPY       300
      PERLND     602
      PERLND     603
      PERLND     604
      PERLND     605
      PERLND     606
      PERLND     607
      PERLND     608
      PERLND     609
      PERLND     610
      PERLND     611
      IMPLND     601
      IMPLND     602
      RCHRES       8
      GENER        9
      GENER       10
    COPY     14
      COPY       400

    END INGRP

END OPN SEQUENCE

PERLND
  ACTIVITY
    #    # ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC   ***
  402  711    1    1    1    1    1    1    1    0    0    0    0    0
  END ACTIVITY

  PRINT-INFO
    #    # ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC *********
```

```
  402  711    6    5    5    5    6    6    5    0    0    0    0    0    0   12
  END PRINT-INFO

  GEN-INFO
    #    #      NAME          NBLKS  UCI   IN  OUT ENGL METR  ***
  702     RESIDENTIAL-SEPTIC      1    1    1    1   90    0
  703     RESIDENTIAL-SEWER       1    1    1    1   90    0
  704     COMMERCIAL/INDUSTRY     1    1    1    1   90    0
  705     AGRICULTURAL-COWS       1    1    1    1   90    0
  706     AGRICULTURAL-CROPS      1    1    1    1   90    0
  707     AGRICULTURAL-MUSHROOM   1    1    1    1   90    0
  708     FOREST                  1    1    1    1   90    0
  709     OPEN LAND               1    1    1    1   90    0
  710     WETLANDS, WATER         1    1    1    1   90    0
  711     undesignated use        1    1    1    1   90    0
  402     RESIDENTIAL-SEPTIC      1    1    1    1   90    0
  403     RESIDENTIAL-SEWER       1    1    1    1   90    0
  404     COMMERCIAL/INDUSTRY     1    1    1    1   90    0
  405     AGRICULTURAL-COWS       1    1    1    1   90    0
  406     AGRICULTURAL-CROPS      1    1    1    1   90    0
  407     AGRICULTURAL-MUSHROOM   1    1    1    1   90    0
  408     FOREST                  1    1    1    1   90    0
  409     OPEN LAND               1    1    1    1   90    0
  410     WETLANDS, WATER         1    1    1    1   90    0
  411     undesignated use        1    1    1    1   90    0
  602     RESIDENTIAL-SEPTIC      1    1    1    1   90    0
  603     RESIDENTIAL-SEWER       1    1    1    1   90    0
  604     COMMERCIAL/INDUSTRY     1    1    1    1   90    0
  605     AGRICULTURAL-COWS       1    1    1    1   90    0
  606     AGRICULTURAL-CROPS      1    1    1    1   90    0
  607     AGRICULTURAL-MUSHROOM   1    1    1    1   90    0
  608     FOREST                  1    1    1    1   90    0
  609     OPEN LAND               1    1    1    1   90    0
  610     WETLANDS, WATER         1    1    1    1   90    0
  611     undesignated use        1    1    1    1   90    0
  END GEN-INFO

**** AIR TEMPERATURE ****

  ATEMP-DAT
             ELDAT    AIRTMP ***
    #    #      (ft)   (deg F) ***
  702  711    -290.0      48.3
  402  411    -390.0      48.3
  602  611      50.0      53.6
  END ATEMP-DAT

**** SNOW ****

  ICE-FLAG
*** <PLS > ICEFG
*** #    #
  402  711    1
  END ICE-FLAG

  SNOW-PARM1
*** <PLS >       LAT     MELEV     SHADE    SNOWCF    COVIND
*** #    #     (deg)      (ft)                          (in)
  702  711      39.9      350.      0.20       1.0      0.60
  402  411      39.8      250.      0.40       1.0      0.60
  602  611      39.7      125.      0.40       1.0      0.60
  END SNOW-PARM1

  SNOW-PARM2
*** <PLS >     RDSCN     TSNOW    SNOEVP    CCFACT    MWATER    MGMELT
*** #    #              (degF)                                (in/day)
  702  711      0.15      30.0      0.08      0.60      0.03     0.010
  402  411      0.15      30.0      0.08      0.60      0.03     0.020
  602  611      0.15      30.0      0.08      0.60      0.03     0.030
  END SNOW-PARM2

**** HYDROLOGY ****
  PWAT-PARM1
*** <PLS >                   Flags
*** x -  x CSNO RTOP UZFG  VCS  VUZ  VNN VIFW VIRC  VLE IFFC
  702         1    0    0    1    0    0    0    1    1    1
  703         1    0    0    1    0    0    0    1    1    1
  704         1    0    0    1    0    0    0    1    1    1
  705         1    0    0    1    0    0    0    1    1    1
  706         1    0    0    1    0    0    0    1    1    1
  707         1    0    0    1    0    0    0    1    1    1
  708         1    0    0    1    0    0    0    1    1    1
  709         1    0    0    1    0    0    0    1    1    1
  710         1    0    0    0    0    0    0    1    0    1
  711         1    0    0    1    0    0    0    1    1    1
  402         1    0    0    1    0    0    0    0    1    1
  403         1    0    0    1    0    0    0    0    1    1
  404         1    0    0    1    0    0    0    0    1    1
  405         1    0    0    1    0    0    0    0    1    1
  406         1    0    0    1    0    0    0    0    1    1
  407         1    0    0    1    0    0    0    0    1    1
  408         1    0    0    1    0    0    0    0    1    1
```

```
  409         1    0    0    1    0    0    0    0    1    1
  410         1    0    0    0    0    0    0    0    0    1
  411         1    0    0    1    0    0    0    0    1    1
  602         1    0    0    1    0    0    0    0    1    1
  603         1    0    0    1    0    0    0    0    1    1
  604         1    0    0    1    0    0    0    0    1    1
  605         1    0    0    1    0    0    0    0    1    1
  606         1    0    0    1    0    0    0    0    1    1
  607         1    0    0    1    0    0    0    0    1    1
  608         1    0    0    1    0    0    0    0    1    1
  609         1    0    0    1    0    0    0    0    1    1
  610         1    0    0    0    0    0    0    0    0    1
  611         1    0    0    1    0    0    0    0    1    1
  END PWAT-PARM1

  PWAT-PARM2
***  <PLS>    FOREST      LZSN    INFILT      LSUR     SLSUR     KVARY     AGWRC
***  x - x                (in)   (in/hr)      (ft)              (1/in)   (1/day)
  702           0.0     8.500     0.100     275.0    0.1962     0.000     0.990
  703           0.0     8.500     0.100     275.0    0.1908     0.000     0.990
  704           0.0     8.500     0.100     275.0    0.1944     0.000     0.990
  705           0.0     8.500     0.110     275.0    0.1727     0.000     0.990
  706           0.0     8.500     0.110     275.0    0.1727     0.000     0.990
  707           0.0     8.500     0.070     275.0    0.1727     0.000     0.990
  708           0.0     8.500     0.150     275.0    0.1980     0.000     0.990
  709           0.0     8.500     0.120     275.0    0.1962     0.000     0.990
  710           0.0     8.500     0.100     275.0    0.1835     0.000     0.990
  711           0.0     8.500     0.120     275.0    0.1763     0.000     0.990
  402           0.0     8.500     0.100     600.0    0.2717     0.000     0.985
  403           0.0     8.500     0.100     600.0    0.1370     0.000     0.985
  404           0.0     8.500     0.100     600.0    0.1530     0.000     0.985
  405           0.0     8.500     0.110     600.0    0.2642     0.000     0.985
  406           0.0     8.500     0.110     600.0    0.2642     0.000     0.985
  407           0.0     8.500     0.070     600.0    0.2642     0.000     0.985
  408           0.0     8.500     0.150     600.0    0.3620     0.000     0.985
  409           0.0     8.500     0.120     600.0    0.2272     0.000     0.985
  410           0.0     8.500     0.100     600.0    0.1799     0.000     0.985
  411           0.0     8.500     0.120     600.0    0.1281     0.000     0.985
  602           0.0     7.500     0.130     250.0    0.1962     2.000     0.985
  603           0.0     7.500     0.130     250.0    0.1908     2.000     0.985
  604           0.0     7.500     0.130     250.0    0.1944     2.000     0.985
  605           0.0     7.500     0.140     250.0    0.1727     2.000     0.985
  606           0.0     7.500     0.140     250.0    0.1727     2.000     0.985
  607           0.0     7.500     0.100     250.0    0.1727     2.000     0.985
  608           0.0     7.500     0.170     250.0    0.1980     2.000     0.985
  609           0.0     7.500     0.140     250.0    0.1962     2.000     0.985
  610           0.0     7.500     0.100     250.0    0.1835     2.000     0.985
  611           0.0     7.500     0.140     250.0    0.1763     2.000     0.985
  END PWAT-PARM2

  PWAT-PARM3
***  <PLS>    PETMAX    PETMIN    INFEXP    INFILD    DEEPFR    BASETP    AGWETP
***  x - x   (deg F)   (deg F)
  702  709      40.0      36.0       2.0       2.0     0.010     0.055     0.000
  710           40.0      36.0       2.0       2.0     0.010     0.055     0.400
  711           40.0      36.0       2.0       2.0     0.010     0.055     0.000
  402  409      40.0      36.0       2.0       2.0     0.010     0.050     0.000
  410           40.0      36.0       2.0       2.0     0.010     0.050     0.400
  411           40.0      36.0       2.0       2.0     0.010     0.050     0.000
  602  609      40.0      36.0       2.0       2.0     0.000     0.000     0.000
  610           40.0      36.0       2.0       2.0     0.000     0.000     0.400
  611           40.0      36.0       2.0       2.0     0.000     0.000     0.000
  END PWAT-PARM3

  PWAT-PARM4
*** <PLS >     CEPSC      UZSN      NSUR     INTFW       IRC     LZETP
*** x -  x      (in)      (in)                         (1/day)
  702          0.050     0.700      0.35      0.70     0.400     0.600
  703          0.050     0.700      0.30      0.70     0.400     0.600
  704          0.050     0.600      0.25      0.70     0.400     0.600
  705          0.050     0.400      0.20      0.70     0.400     0.700
  706          0.050     0.400      0.30      0.70     0.400     0.700
  707          0.050     0.700      0.30      0.70     0.400     0.700
  708          0.100     1.000      0.35      0.70     0.400     0.800
  709          0.050     0.600      0.30      0.70     0.400     0.600
  710          0.050     1.000      0.05      0.70     0.400     0.900
  711          0.050     0.600      0.30      0.70     0.400     0.600
  402          0.050     0.600      0.35      0.70     0.500     0.600
  403          0.050     0.600      0.35      0.70     0.500     0.600
  404          0.050     0.500      0.25      0.70     0.500     0.600
  405          0.050     0.400      0.20      0.70     0.500     0.700
  406          0.050     0.400      0.30      0.70     0.500     0.700
  407          0.050     0.600      0.30      0.70     0.500     0.700
  408          0.100     0.900      0.35      0.70     0.500     0.800
  409          0.050     0.600      0.30      0.70     0.500     0.600
  410          0.050     1.000      0.05      0.70     0.500     0.900
  411          0.050     0.600      0.30      0.70     0.500     0.600
  602          0.050     0.700      0.35      0.75     0.300     0.600
  603          0.050     0.700      0.30      0.75     0.300     0.600
  604          0.050     0.600      0.25      0.75     0.300     0.600
  605          0.050     0.400      0.20      0.75     0.300     0.700
  606          0.050     0.400      0.30      0.75     0.300     0.700
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  607          0.050     0.700      0.30      0.75     0.300     0.700
  608          0.100     1.000      0.35      0.75     0.300     0.800
  609          0.050     0.600      0.30      0.75     0.300     0.600
  610          0.050     1.000      0.05      0.75     0.300     0.900
  611          0.050     0.600      0.30      0.75     0.300     0.600
  END PWAT-PARM4

  MON-INTERCEP
*** <PLS >  Interception storage capacity at start of each month (in)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  702  704 .040 .040 .060 .080 .100 .100 .100 .100 .080 .060 .040 .040
  705  707 .030 .030 .030 .030 .060 .090 .110 .110 .110 .080 .070 .030
  708      .040 .040 .070 .110 .140 .160 .160 .150 .120 .090 .050 .040
  709  711 .040 .040 .060 .080 .100 .100 .100 .100 .080 .060 .040 .040
  402  404 .040 .040 .060 .080 .100 .100 .100 .100 .080 .060 .040 .040
  405  407 .030 .030 .030 .030 .060 .090 .110 .110 .110 .080 .070 .030
  408      .040 .040 .070 .110 .140 .160 .160 .150 .120 .090 .050 .050
  409  411 .040 .040 .060 .080 .100 .100 .100 .100 .080 .060 .040 .040
  602  604 .040 .040 .060 .080 .100 .100 .100 .100 .080 .060 .040 .040
  605  607 .030 .030 .030 .030 .060 .090 .110 .110 .110 .080 .070 .030
  608      .040 .040 .070 .110 .140 .160 .160 .150 .120 .090 .050 .040
  609  611 .040 .040 .060 .080 .100 .100 .100 .100 .080 .060 .060 .060
  END MON-INTERCEP

  MON-UZSN
*** <PLS >  Upper zone storage at start of each month  (inches)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  705  706 .350 .350 .400 .430 .450 .450 .400 .400 .400 .400 .350 .350
  405  406 .350 .350 .400 .430 .450 .450 .400 .400 .400 .400 .350 .350
  605  606 .350 .350 .400 .430 .450 .450 .400 .400 .400 .400 .350 .350
  END MON-UZSN

  MON-IRC
***
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  402  711  0.3  0.3  0.3  0.3  0.4  0.5  0.7  0.7  0.5  0.5  0.4  0.3
  END MON-IRC

  MON-LZETPARM
*** <PLS >  Lower zone evapotransp   parm at start of each month
  702  707  0.7  0.7  0.7  0.7  0.7  0.7  0.7  0.7  0.0  0.3  0.7  0.7
  708       0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.0  0.4  0.8  0.8
  709  711  0.7  0.7  0.7  0.7  0.7  0.7  0.7  0.7  0.0  0.3  0.7  0.7
  402  407  0.7  0.7  0.7  0.7  0.7  0.7  0.7  0.7  0.0  0.2  0.7  0.7
  408       0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.0  0.3  0.8  0.8
  409  411  0.7  0.7  0.7  0.7  0.7  0.7  0.7  0.7  0.0  0.2  0.7  0.7
  602  607  0.7  0.7  0.7  0.7  0.7  0.7  0.7  0.7  0.0  0.2  0.7  0.7
  608       0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.0  0.3  0.8  0.8
  609  611  0.7  0.7  0.7  0.7  0.7  0.7  0.7  0.7  0.0  0.2  0.7  0.7
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  END MON-LZETPARM

  PWAT-STATE1
***  <PLS>  PWATER state variables (in)
***  x - x      CEPS      SURS       UZS      IFWS       LZS      AGWS      GWVS
  702            0.0      0.00       .70       0.0       7.5       1.8       0.0
  703            0.0      0.00       .70       0.0       7.5       1.8       0.0
  704            0.0      0.00       .60       0.0       7.5       1.8       0.0
  705            0.0      0.00       .40       0.0       7.5       1.8       0.0
  706            0.0      0.00       .40       0.0       7.5       1.8       0.0
  707            0.0      0.00       .70       0.0       7.5       1.8       0.0
  708            0.0      0.00      1.00       0.0       7.5       1.8       0.0
  709            0.0      0.00       .60       0.0       7.5       1.8       0.0
  710            0.0         0       .90       0.0       7.5       1.8       0.0
  711            0.0      0.00       .60       0.0       7.0       1.8       0.0
  402            0.0      0.00       .80       0.0       7.0       1.8       0.0
  403            0.0      0.00       .80       0.0       7.0       1.8       0.0
  404            0.0      0.00       .70       0.0       7.0       1.8       0.0
  405            0.0      0.00       .40       0.0       7.0       1.8       0.0
  406            0.0      0.00       .40       0.0       7.0       1.8       0.0
  407            0.0      0.00       .70       0.0       7.0       1.8       0.0
  408            0.0      0.00      1.20       0.0       7.0       1.8       0.0
  409            0.0      0.00       .70       0.0       7.0       1.8       0.0
  410            0.0         0       .90       0.0       7.0       1.8       0.0
  411            0.0      0.00       .70       0.0       7.0       1.8       0.0
  602            0.0      0.00       .50       0.0       7.0       1.5       0.0
  603            0.0      0.00       .50       0.0       7.0       1.5       0.0
  604            0.0      0.00       .50       0.0       7.0       1.5       0.0
  605            0.0      0.00       .40       0.0       7.0       1.5       0.0
  606            0.0      0.00       .40       0.0       7.0       1.5       0.0
  607            0.0      0.00       .50       0.0       7.0       1.5       0.0
  608            0.0      0.00       .70       0.0       7.0       1.5       0.0
  609            0.0      0.00       .50       0.0       7.0       1.5       0.0
  610            0.0         0       .90       0.0       7.0       1.5       0.0
  611            0.0      0.00       .50       0.0       7.0       1.5       0.0
  END PWAT-STATE1


  SED-PARM1
*** <PLS >  Sediment parameters 1
*** x -  x  CRV VSIV SDOP
  402  711    1    0    1
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  END SED-PARM1

  SED-PARM2
*** <PLS >      SMPF      KRER      JRER     AFFIX     COVER      NVSI
*** x -  x                               (/day)           lb/ac-day
  702  703     1.000     0.500     2.000     0.010     0.000     1.000
  704          1.000     0.500     2.000     0.010     0.000     1.000
  705  706     1.000     0.500     2.000     0.010     0.000     1.000
  707          1.000     0.500     2.000     0.010     0.000     1.000
  708          1.000     0.450     2.000     0.002     0.000     2.000
  709          1.000     0.500     2.000     0.010     0.000     2.000
  710          1.000     0.400     2.000     0.002     0.000     2.000
  711          1.000     0.500     2.000     0.010     0.000     2.000
  402  403     1.000     0.500     2.000     0.010     0.000     1.000
  404          1.000     0.500     2.000     0.010     0.000     1.000
  405  406     1.000     0.520     2.000     0.010     0.000     1.000
  407          1.000     0.520     2.000     0.010     0.000     1.000
  408          1.000     0.450     2.000     0.002     0.000     2.000
  409          1.000     0.500     2.000     0.010     0.000     2.000
  410          1.000     0.400     2.000     0.002     0.000     2.000
  411          1.000     0.500     2.000     0.010     0.000     2.000
  602  603     1.000     0.500     2.000     0.010     0.000     1.000
  604          1.000     0.500     2.000     0.010     0.000     1.000
  605  606     1.000     0.520     2.000     0.010     0.000     1.000
  607          1.000     0.520     2.000     0.010     0.000     1.000
  608          1.000     0.450     2.000     0.002     0.000     2.000
  609          1.000     0.500     2.000     0.010     0.000     2.000
  610          1.000     0.400     2.000     0.002     0.000     2.000
  611          1.000     0.450     2.000     0.010     0.000     2.000
  END SED-PARM2

  SED-PARM3
*** <PLS >  Sediment parameter 3
*** x -  x      KSER      JSER      KGER      JGER
  702          0.250     1.800     0.010     2.000
  703          0.350     1.800     0.020     2.000
  704          0.550     1.800     0.045     2.000
  705  706     2.150     1.800     0.035     2.000
  707          2.350     1.800     0.035     2.000
  708          0.145     1.800     0.000     2.000
  709          0.350     1.800     0.004     2.000
  710          0.008     1.800     0.000     2.000
  711          0.350     1.800     0.004     2.000
  402          0.250     1.800     0.010     2.000
  403          0.350     1.800     0.020     2.000
  404          0.550     1.800     0.045     2.000
  405  406     2.150     1.800     0.035     2.000
  407          2.350     1.800     0.035     2.000
  408          0.145     1.800     0.000     2.000
  409          0.350     1.800     0.004     2.000
  410          0.010     1.800     0.000     2.000
  411          0.350     1.800     0.004     2.000
  602          0.350     1.800     0.015     2.000
  603          0.550     1.800     0.025     2.000
  604          0.800     1.800     0.065     2.000
  605  606     2.600     1.800     0.055     2.000
  607          2.800     1.800     0.055     2.000
  608          0.250     1.800     0.000     2.000
  609          0.500     1.800     0.005     2.000
  610          0.008     1.800     0.000     2.000
  611          0.500     1.800     0.005     2.000
  END SED-PARM3

  MON-COVER
*** <PLS >  Monthly values for erosion related cover
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  702  704 0.90 0.90 0.90 0.91 0.93 0.93 0.93 0.93 0.93 0.91 0.90 0.90
  705  706 0.50 0.45 0.20 0.10 0.15 0.45 0.65 0.65 0.65 0.60 0.60 0.55
  707      0.50 0.45 0.10 0.10 0.10 0.50 0.50 0.50 0.50 0.50 0.50 0.50
***  705  707 0.50 0.45 0.00 0.00 0.10 0.50 0.75 0.93 0.93 0.85 0.70 0.55
  708      0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97
  709      0.90 0.90 0.90 0.90 0.92 0.93 0.93 0.93 0.93 0.91 0.90 0.90
  710      0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97
  711      0.90 0.90 0.90 0.90 0.92 0.93 0.93 0.93 0.93 0.91 0.90 0.90
  402  404 0.90 0.90 0.90 0.91 0.93 0.93 0.93 0.93 0.93 0.91 0.90 0.90
  405  406 0.50 0.45 0.20 0.10 0.15 0.45 0.65 0.65 0.65 0.60 0.60 0.55
  407      0.50 0.45 0.10 0.10 0.10 0.50 0.50 0.50 0.50 0.50 0.50 0.50
***  405  407 0.50 0.45 0.00 0.00 0.10 0.50 0.75 0.93 0.93 0.85 0.70 0.55
  408      0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97
  409      0.90 0.90 0.90 0.90 0.92 0.93 0.93 0.93 0.93 0.91 0.90 0.90
  410      0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97
  411      0.90 0.90 0.90 0.90 0.92 0.93 0.93 0.93 0.93 0.91 0.90 0.90
  602  604 0.90 0.90 0.90 0.91 0.93 0.93 0.93 0.93 0.93 0.91 0.90 0.90
  605  606 0.50 0.45 0.20 0.10 0.15 0.45 0.65 0.65 0.65 0.60 0.60 0.55
  607      0.50 0.45 0.10 0.10 0.10 0.50 0.50 0.50 0.50 0.50 0.50 0.50
***  605  607 0.50 0.45 0.00 0.00 0.10 0.50 0.75 0.93 0.93 0.85 0.70 0.55
  608      0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97
  609      0.90 0.90 0.90 0.90 0.92 0.93 0.93 0.93 0.93 0.91 0.90 0.90
  610      0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97 0.97
  611      0.90 0.90 0.90 0.90 0.92 0.93 0.93 0.93 0.93 0.91 0.90 0.90
  END MON-COVER
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  SED-STOR
*** <PLS >  Detached sediment storage (tons/acre)
*** x -  x      DETS
  402  711    0.4000
  END SED-STOR

  PSTEMP-PARM1
*** <PLS >  Flags for section PSTEMP
*** x -  x SLTV ULTV LGTV TSOP
  402  711    1    1    0    1
  END PSTEMP-PARM1

  PSTEMP-PARM2
PERLND ***      ASLT      BSLT     ULTP1     ULTP2     LGTP1     LGTP2
  402  711      32.0      0.50      32.0      0.90      54.0       0.0
  END PSTEMP-PARM2

  MON-ASLT
PERLND ***  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  402  711 32.9 35.3 37.9 42.7 46.9 52.6 55.0 54.3 51.4 46.3 40.5 36.6
  END MON-ASLT

  MON-BSLT
PERLND ***  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  402  711 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23 0.23
  END MON-BSLT

  MON-ULTP1
PERLND ***  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  402  711 40.0 41.0 43.0 46.0 48.6 52.8 56.8 57.8 53.5 48.8 45.0 42.0
  END MON-ULTP1

  MON-ULTP2
PERLND ***  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  402  711 0.10 0.10 0.10 0.10 0.10 0.10 0.10 0.10 0.10 0.10 0.10 0.10
  END MON-ULTP2

  PSTEMP-TEMPS
PERLND ***     AIRTC     SLTMP     ULTMP     LGTMP
  402  711      50.0      60.0      57.0      53.0
  END PSTEMP-TEMPS

  PWT-PARM2
PERLND ***      ELEV     IDOXP     ICO2P     ADOXP     ACO2P
  402  711      400.      8.80         0      8.80         0
  END PWT-PARM2

  MON-IFWDOX
PERLND ***  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  402  711 11.0 10.0 10.0 10.0 9.00 7.00 6.00 6.00 7.00 9.00 10.0 11.0
  END MON-IFWDOX

  MON-GRNDDOX
PERLND ***  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  402  711 11.0 10.0 10.0 10.0 9.00 7.00 6.00 6.00 7.00 9.00 10.0 11.0
  END MON-GRNDDOX

  PWT-TEMPS
PERLND ***     SOTMP     IOTMP     AOTMP
  402  711       60.       57.       53.
  END PWT-TEMPS

  PWT-GASES
PERLND ***     SODOX     SOCO2     IODOX     IOCO2     AODOX     AOCO2
  402  711       8.8         0       8.8         0       8.8         0
  END PWT-GASES

*** Water Quality Constituents N and P ***
  NQUALS
    #    # NQAL  ***
  402  711    5
  END NQUALS

  QUAL-PROPS
    #    #<--QUALID-->    QTID  QSD VPFW VPFS  QSO  VQO QIFW VIQC QAGW VAQC  ***
  402  711         NO3     LBS    1    2    0    0    0    1    4    1    4
  END QUAL-PROPS

  QUAL-INPUT
    #    #     SQO   POTFW   POTFS   ACQOP  SQOLIM   WSQOP    IOQC    AOQC  ***
  402        0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
  403        0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
  404        0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
  405        0.100      1.      1.  0.0411  0.7500   0.500      1.      1. ***
  406        0.100      1.      1.  0.0411  0.7500   0.500      1.      1. ***
  407        0.100      1.      1.  0.0411  0.7500   0.500      1.      1. ***
  408        0.100      1.      1.  0.0137  0.2500   0.500      1.      1. ***
  409        0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
  410        0.100      1.      1.  0.0137  0.2500   0.500      1.      1. ***
  411        0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
  702        0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
  703        0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
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```
  704        0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
  705        0.100      1.      1.  0.0411  0.7500   0.500      1.      1. ***
  706        0.100      1.      1.  0.0411  0.7500   0.500      1.      1. ***
  707        0.100      1.      1.  0.0411  0.7500   0.500      1.      1. ***
  708        0.100      1.      1.  0.0137  0.2500   0.500      1.      1. ***
  709        0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
  710        0.100      1.      1.  0.0137  0.2500   0.500      1.      1. ***
  711        0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
  602        0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
  603        0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
  604        0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
  605        0.100      1.      1.  0.0411  0.7500   0.500      1.      1. ***
  606        0.100      1.      1.  0.0411  0.7500   0.500      1.      1. ***
  607        0.100      1.      1.  0.0411  0.7500   0.500      1.      1. ***
  608        0.100      1.      1.  0.0137  0.2500   0.500      1.      1. ***
  609        0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
  610        0.100      1.      1.  0.0137  0.2500   0.500      1.      1. ***
  611        0.100      1.      1.  0.0274  0.5000   0.500      1.      1. ***
  END QUAL-INPUT

  MON-POTFW
            Potency factors for NO3 (lb NO3-N/ton sediment)             ***
    #    #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
  402       1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5
  702       1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5
  602       1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5
  403       1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4
  703       1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4
  603       1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4
  404       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
  704       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
  604       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
  405       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
  705       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
  605       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
*** reduce no3 load for lower intensity ag in 400 series crop (hay)
  406       1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4  1.4
*** original estimate for 406 soil no3
  406 ***   1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
  706       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
  606       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
  407       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
  707       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
  607       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
  408        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
  708        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
  608        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
  409        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
  709        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
  609        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
  410        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
  710        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
  610        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
  411        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
  711        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
  611        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
  END MON-POTFW

  MON-IFLW-CONC
            Interflow concentration of NO3-N (mg/l)                     ***
    #    #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
  402       3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5
  702       3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5
  602       3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5
  403       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
  703       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
  603       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
  404       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
  704       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
  604       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
  405       6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0
  705       6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0
  605       6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0
*** reduce no3 load for lower intensity ag in 400 series crop (hay)
  406       3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5
***original estimate for 406 inreflow no3
  406   *** 5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0
  706       5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0
  606       5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0
  407       8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0
  707       8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0
  607       8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0
  408      .400 .400 .400 .350 .350 .300 .300 .250 .300 .300 .350 .400
  708      .400 .400 .400 .350 .350 .300 .300 .250 .300 .300 .350 .400
  608      .400 .400 .400 .350 .350 .300 .300 .250 .300 .300 .350 .400
  409       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
  709       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
  609       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
  410      .700 .680 .600 .570 .530 .470 .430 .360 .430 .500 .570 .640
  710      .700 .680 .600 .570 .530 .470 .430 .360 .430 .500 .570 .640
  610      .700 .680 .600 .570 .530 .470 .430 .360 .430 .500 .570 .640
  411       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
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  711       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
  611       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
  END MON-IFLW-CONC

  MON-GRND-CONC
            Active groundwater concentration of NO3-N (mg/l)            ***
    #    # JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
  402       3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5
  702       3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5
  602       3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5
  403       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
  703       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
  603       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
  404       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
  704       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
  604       1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8  1.8
  405       6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0
  705       6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0
  605       6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0  6.0
*** reduce no3 load for lower intensity ag in 400 series crop (hay)
  406       3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5  3.5
***original estimate for 406 gw no3
  406   *** 5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0
  706       5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0
  606       5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0
  407       8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0
  707       8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0
  607       8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0  8.0
  408      .400 .400 .400 .350 .350 .300 .300 .250 .300 .300 .350 .400
  708      .400 .400 .400 .350 .350 .300 .300 .250 .300 .300 .350 .400
  608      .400 .400 .400 .350 .350 .300 .300 .250 .300 .300 .350 .400
  409       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
  709       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
  609       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
  410      .700 .680 .600 .570 .530 .470 .430 .360 .430 .500 .570 .640
  710      .700 .680 .600 .570 .530 .470 .430 .360 .430 .500 .570 .640
  610      .700 .680 .600 .570 .530 .470 .430 .360 .430 .500 .570 .640
  411       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
  711       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
  611       1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2  1.2
  END MON-GRND-CONC

  QUAL-PROPS
    #    #<--QUALID-->    QTID  QSD VPFW VPFS  QSO  VQO QIFW VIQC QAGW VAQC  ***
  402  711         NH4     LBS    1    2    0    0    0    1    4    1    4
  END QUAL-PROPS

  MON-POTFW
            Potency factors for NH4 (lb NH4-N/ton sediment)             ***
    #    # JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
  402       .24  .24  .24  .24  .24  .24  .24  .24  .24  .24  .24  .24
  702       .24  .24  .24  .24  .24  .24  .24  .24  .24  .24  .24  .24
  602       .24  .24  .24  .24  .24  .24  .24  .24  .24  .24  .24  .24
  403       .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10
  703       .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10
  603       .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10
  404       .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10
  704       .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10
  604       .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10
  405       .30  .30  .30  .30  .30  .30  .30  .30  .30  .30  .30  .30
  705       .40  .40  .40  .40  .40  .40  .40  .40  .40  .40  .40  .40
  605       .30  .30  .30  .30  .30  .30  .30  .30  .30  .30  .30  .30
  406       .15  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15
  706       .30  .30  .30  .30  .30  .30  .30  .30  .30  .30  .30  .30
  606       .15  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15
  407       1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5
  707       1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5  1.5
  607       .95  .95  .95  .95  .95  .95  .95  .95  .95  .95  .95  .95
  408      .002 .002 .002 .002 .002 .002 .002 .002 .002 .002 .002 .002
  708      .002 .002 .002 .002 .002 .002 .002 .002 .002 .002 .002 .002
  608      .002 .002 .002 .002 .002 .002 .002 .002 .002 .002 .002 .002
  409       .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10
  709       .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10
  609       .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10
  410      .002 .002 .002 .002 .002 .002 .002 .002 .002 .002 .002 .002
  710      .002 .002 .002 .002 .002 .002 .002 .002 .002 .002 .002 .002
  610      .002 .002 .002 .002 .002 .002 .002 .002 .002 .002 .002 .002
  411       .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10
  711       .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10
  611       .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10  .10
  END MON-POTFW

  MON-IFLW-CONC
            Interflow concentration of NH4-N (mg/l)                     ***
    #    # JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
  402      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
  702      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
  602      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
  403      .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015
  703      .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015
  603      .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015
  404      .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015
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704      .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015
604      .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015
405      .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028
705      .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028
605      .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028
406      .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028
706      .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028
606      .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028
407      .080 .080 .080 .080 .080 .080 .080 .080 .080 .080 .080 .080
707      .150 .150 .150 .150 .150 .150 .150 .150 .150 .150 .150 .150
607      .080 .080 .080 .080 .080 .080 .080 .080 .080 .080 .080 .080
408      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
708      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
608      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
409      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
709      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
609      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
410      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
710      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
610      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
411      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
711      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
611      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
END MON-IFLW-CONC

MON-GRND-CONC
          Active groundwater concentration of NH4-N (mg/l)            ***
  #    #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
402      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
702      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
602      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
403      .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015
703      .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015
603      .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015
404      .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015
704      .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015
604      .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015 .015
405      .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028
705      .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028
605      .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028
406      .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028
706      .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028
606      .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028 .028
407      .050 .050 .050 .050 .050 .050 .050 .050 .050 .050 .050 .050
707      .060 .060 .060 .060 .060 .060 .060 .060 .060 .060 .060 .060
607      .050 .050 .050 .050 .050 .050 .050 .050 .050 .050 .050 .050
408      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
708      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
608      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
409      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
709      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
609      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
410      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
710      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
610      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
411      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
711      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
611      .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027 .027
END MON-GRND-CONC

QUAL-PROPS
  #    #<--QUALID-->    QTID  QSD VPFW VPFS  QSO  VQO QIFW VIQC QAGW VAQC  ***
402  711         PO4     LBS    1    2    0    0    0    1    4    1    4
END QUAL-PROPS

MON-POTFW
          Potency factors for PO4 (lb PO4-P/ton sediment)             ***
  #    #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
402       0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6
702       0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6
602       0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6
403       0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6
703       0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6
603       0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6
404       0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6
704       0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6
604       0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6
405       4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0
705       4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0
605       4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0
406       4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0
706       4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0
606       4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0
407       14.  14.  14.  14.  14.  14.  14.  14.  14.  14.  14.  14.
707       14.  14.  14.  14.  14.  14.  14.  14.  14.  14.  14.  14.
607       14.  14.  14.  14.  14.  14.  14.  14.  14.  14.  14.  14.
408      .010 .010 .010 .010 .010 .025 .035 .035 .025 .010 .010 .010
708      .010 .010 .010 .010 .010 .025 .035 .035 .025 .010 .010 .010
608      .010 .010 .010 .010 .010 .025 .035 .035 .025 .010 .010 .010
409       0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8
709       0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8
609       0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8
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410      .020 .020 .020 .020 .020 .025 .035 .035 .035 .020 .020 .020
710      .020 .020 .020 .020 .020 .025 .035 .035 .025 .020 .020 .020
610      .020 .020 .020 .020 .020 .025 .035 .035 .025 .020 .020 .020
411       0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8
711       0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8
611       0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8  0.8
END MON-POTFW

MON-IFLW-CONC
          Interflow concentration of PO4-P (mg/l)                     ***
  #    #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
402      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
702      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
602      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
403      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
703      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
603      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
404      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
704      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
604      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
405      .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040
705      .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040
605      .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040
406      .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040
706      .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040
606      .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040
407      .120 .120 .120 .120 .120 .120 .120 .120 .120 .120 .120 .120
707      .120 .120 .120 .120 .120 .120 .120 .120 .120 .120 .120 .120
607      .120 .120 .120 .120 .120 .120 .120 .120 .120 .120 .120 .120
408      .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005
708      .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005
608      .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005
409      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
709      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
609      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
410      .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005
710      .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005
610      .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005
411      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
711      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
611      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
END MON-IFLW-CONC

MON-GRND-CONC
          Active groundwater concentration of PO4-P (mg/l)            ***
  #    #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
402      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
702      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
602      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
403      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
703      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
603      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
404      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
704      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
604      .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025 .025
405      .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040
705      .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040
605      .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040
406      .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040
706      .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040
606      .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040 .040
407      .060 .060 .060 .060 .060 .060 .060 .060 .060 .060 .060 .060
707      .070 .070 .070 .070 .070 .070 .070 .070 .070 .070 .070 .070
607      .060 .060 .060 .060 .060 .060 .060 .060 .060 .060 .060 .060
408      .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005
708      .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005
608      .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005
409      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
709      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
609      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
410      .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005
710      .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005
610      .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005 .005
411      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
711      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
611      .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010 .010
END MON-GRND-CONC

QUAL-PROPS
  #    #<--QUALID-->    QTID  QSD VPFW VPFS  QSO  VQO QIFW VIQC QAGW VAQC  ***
402  711         BOD     LBS    1    2    0    0    0    1    4    1    4
END QUAL-PROPS

MON-POTFW
          Potency factors for BOD (lb BOD/ton sediment)             ***
  #    #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
402       25.  25.  25.  25.  25.  25.  25.  25.  25.  25.  25.  25.
702       25.  25.  25.  25.  25.  25.  25.  25.  25.  25.  25.  25.
402       25.  25.  25.  25.  25.  25.  25.  25.  25.  25.  25.  25.
403       20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.
703       20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.
603       20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.
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404       20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.
704       20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.
604       20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.
405       35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.
705       35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.
605       35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.
406       35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.
706       35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.
606       35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.
407       35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.
707       35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.
607       35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.  35.
408       8.5  8.5  8.5  8.5  8.5  5.5  5.5  5.5  5.5  8.5  8.5  8.5
708       8.5  8.5  8.5  8.5  8.5  5.5  5.5  5.5  5.5  8.5  8.5  8.5
608       8.5  8.5  8.5  8.5  8.5  5.5  5.5  5.5  5.5  8.5  8.5  8.5
409       20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.
709       20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.
609       20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.
410       8.5  8.5  8.5  8.5  8.5  5.5  5.5  5.5  5.5  8.5  8.5  8.5
710       8.5  8.5  8.5  8.5  8.5  5.5  5.5  5.5  5.5  8.5  8.5  8.5
610       8.5  8.5  8.5  8.5  8.5  5.5  5.5  5.5  5.5  8.5  8.5  8.5
411       20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.
711       20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.
611       20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.  20.
END MON-POTFW

MON-IFLW-CONC
          Interflow concentration of BOD (mg/l)                       ***
  #    #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
402       .65  .65  .65  .65  .65  .65  .65  .65  .65  .65  .65  .65
702       .65  .65  .65  .65  .65  .65  .65  .65  .65  .65  .65  .65
602       .65  .65  .65  .65  .65  .65  .65  .65  .65  .65  .65  .65
403        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
703        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
603        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
404        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
704        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
604        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
405        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
705        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
605        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
406        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
706        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
606        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
407        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
707        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
607        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
408        .5   .5   .5   .5   .5   .5   .5   .5   .5   .5   .5   .5
708        .5   .5   .5   .5   .5   .5   .5   .5   .5   .5   .5   .5
608        .5   .5   .5   .5   .5   .5   .5   .5   .5   .5   .5   .5
409        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
709        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
609        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
410        .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1
710        .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1
610        .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1
411        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
711        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
611        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
END MON-IFLW-CONC

MON-GRND-CONC
          Active groundwater concentration of BOD (mg/l)              ***
  #    #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
402       .65  .65  .65  .65  .65  .65  .65  .65  .65  .65  .65  .65
702       .65  .65  .65  .65  .65  .65  .65  .65  .65  .65  .65  .65
602       .65  .65  .65  .65  .65  .65  .65  .65  .65  .65  .65  .65
403        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
703        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
603        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
404        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
704        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
604        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
405        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
705        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
605        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
406        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
706        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
606        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
407        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
707        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
607        2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.   2.
408        .5   .5   .5   .5   .5   .5   .5   .5   .5   .5   .5   .5
708        .5   .5   .5   .5   .5   .5   .5   .5   .5   .5   .5   .5
608        .5   .5   .5   .5   .5   .5   .5   .5   .5   .5   .5   .5
409        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
709        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
609        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
410        .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1
710        .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1
610        .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1
411        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
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  711        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
  611        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
  END MON-GRND-CONC

  QUAL-PROPS
    #    #<--QUALID-->    QTID  QSD VPFW VPFS  QSO  VQO QIFW VIQC QAGW VAQC  ***
  402  711        ORGN     LBS    1    1    0    0    0    1    4    1    4
  END QUAL-PROPS

  MON-POTFW
            Potency factors for ORGN (lb ORGN/ton sediment)             ***
  402       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
  702       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
  602       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
  403       1.3  1.3  1.3  1.3  1.3  1.3  1.3  1.3  1.3  1.3  1.3  1.3
  703       1.3  1.3  1.3  1.3  1.3  1.3  1.3  1.3  1.3  1.3  1.3  1.3
  603        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
  404        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
  704        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
  604        1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.   1.
  405       4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0
  705       4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0
  605       4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0  4.0
  406       3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0
  306       3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0
  606       3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0  3.0
  407       5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0
  707       5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0
  607       5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0  5.0
  408       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
  708       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
  608       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
  409       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
  709       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
  609       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
  410       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
  710       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
  610       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
  411       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
  711       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
  611       2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0  2.0
  END MON-POTFW

  MON-IFLW-CONC
            Interflow concentration of ORGN (mg/l)                      ***
    #    #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
  402       .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25
  702       .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25
  602       .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25
  403        .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2
  703        .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2
  603        .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2
  404        .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2
  704        .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2
  604        .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2
  405        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
  705        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
  605        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
  406        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
  706        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
  606        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
  407        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
  707        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
  607        .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6   .6
  408        .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2
  708        .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2
  608        .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2   .2
  409       .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25
  709       .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25
  609       .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25
  410        .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1
  710        .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1
  610        .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1
  411       .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25
  711       .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25
  611       .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25  .25
  END MON-IFLW-CONC

  MON-GRND-CONC
            Active groundwater concentration of ORGN (mg/l)             ***
    #    #  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC  ***
  402  811  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15  .15
  END MON-GRND-CONC

END PERLND

IMPLND
  ACTIVITY
    #    # ATMP SNOW IWAT  SLD  IWG IQAL  ***
  401  702    1    1    1    1    1    1
  END ACTIVITY
```

```
  PRINT-INFO
    #    # ATMP SNOW IWAT  SLD  IWG IQAL PIVL  PYR  ***
  401  702    6    6    5    5    5    5    0   12
  END PRINT-INFO

  GEN-INFO
    #    #      NAME            UCI   IN  OUT ENGL METR  ***
  701     ROADS,BUILDING-resid    1    1    1   90    0
  702     ROADS,BUILDING-urban    1    1    1   90    0
  401     ROADS,BUILDING-resid    1    1    1   90    0
  402     ROADS,BUILDING-urban    1    1    1   90    0
  601     ROADS,BUILDING-resid    1    1    1   90    0
  602     ROADS,BUILDING-urban    1    1    1   90    0
  END GEN-INFO

**** AIR TEMPERATURE ****

  ATEMP-DAT
               ELDAT    AIRTMP ***
    #    #      (ft)   (deg F) ***
  701  702    -290.0      48.3
  401  402    -390.0      48.3
  601  602      50.0      53.6
  END ATEMP-DAT

**** SNOW ****

  ICE-FLAG
*** <ILS > ICEFG
*** #    #
  401  702    1
  END ICE-FLAG

  SNOW-PARM1
*** <ILS >       LAT     MELEV     SHADE    SNOWCF    COVIND
*** #    #     (deg)      (ft)                          (in)
  701  702      39.9      350.      0.20       1.0      0.60
  401  402      39.8      250.      0.20       1.0      0.60
  601  602      39.7      125.      0.20       1.0      0.60
  END SNOW-PARM1

  SNOW-PARM2
*** <ILS >     RDSCN     TSNOW    SNOEVP    CCFACT    MWATER    MGMELT
*** #    #              (degF)                                (in/day)
  701  702      0.15      30.0      0.08      0.60      0.03      0.05
  401  402      0.15      30.0      0.08      0.60      0.03      0.05
  601  602      0.15      30.0      0.08      0.60      0.03      0.05
  END SNOW-PARM2

**** HYDROLOGY ****

  IWAT-PARM1
*** <ILS >        Flags
*** x -  x CSNO RTOP  VRS  VNN RTLI
  401  702    1    0    1    0    0
  END IWAT-PARM1

  IWAT-PARM2
*** <ILS >      LSUR     SLSUR      NSUR     RETSC
*** x -  x      (ft)                          (in)
  701          150.0     0.036      0.07       0.0
  702          150.0     0.031      0.05       0.0
  401          150.0     0.036      0.07       0.0
  402          150.0     0.031      0.05       0.0
  601          150.0     0.036      0.07       0.0
  602          150.0     0.031      0.05       0.0
  END IWAT-PARM2

  IWAT-PARM3
*** <ILS >    PETMAX    PETMIN
*** x -  x   (deg F)   (deg F)
  401  702      40.0      35.0
  END IWAT-PARM3

  MON-RETN
*** <ILS >  Retention storage capacity at start of each month (in)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  401  702  .03  .03  .04  .04  .05 .065 .065 .065  .05  .04  .04  .03
  END MON-RETN

  IWAT-STATE1
*** <ILS >  IWATER state variables (inches)
*** x -  x      RETS      SURS
  401  702       0.0       0.0
  END IWAT-STATE1

  SLD-PARM1
*** <ILS >     Flags
*** x -  x VASD VRSD SDOP
  401  702    0    0    1
  END SLD-PARM1
```

```
  SLD-PARM2
IMPLND ***      KEIM      JEIM    ACCSDP    REMSDP
  701            1.0       1.2    0.0010      0.08
  702            1.0       1.2    0.0040      0.08
  401            1.0       1.2    0.0010      0.08
  402            1.0       1.2    0.0040      0.08
  601            1.0       1.2    0.0010      0.08
  602            1.0       1.2    0.0040      0.08
  END SLD-PARM2

  SLD-STOR
IMPLND ***      SLDS
  401  702      0.05
  END SLD-STOR

  IWT-PARM1
*** <ILS >  Flags for section IWTGAS
*** x -  x WTFV CSNO
  401  702    1    1
  END IWT-PARM1

  IWT-PARM2
IMPLND ***      ELEV      AWTF      BWTF
  701  702      350.      34.0      0.3
  401  402      250.      34.0      0.3
  601  602      125.      34.0      0.3
  END IWT-PARM2

  MON-AWTF
IMPLND ***  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  401  702 32.9 36.0 39.1 45.1 50.3 57.4 60.4 59.6 55.9 49.5 42.4 37.4
  END MON-AWTF

  MON-BWTF
IMPLND ***  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  401  702 0.38 0.38 0.38 0.38 0.38 0.38 0.38 0.38 0.38 0.38 0.38 0.38
  END MON-BWTF

  IWT-INIT
*** <ILS >     SOTMP     SODOX     SOCO2
*** x -  x   (deg F)    (mg/l)  (mg C/l)
  401  702   55.
  END IWT-INIT

*** WATER QUALITY CONSTITUENTS ***

  NQUALS
    #    # NQAL  ***
  401  402    4
  701  702    4
  601  602    4
  END NQUALS

  QUAL-PROPS
    #    #<--QUALID-->    QTID  QSD VPFW  QSO  VQO   ***
  401  402         NO3     LBS    0    0    1    0
  701  702         NO3     LBS    0    0    1    0
  601  602         NO3     LBS    0    0    1    0
  END QUAL-PROPS

  QUAL-INPUT
    #    #     SQO   POTFW   ACQOP  SQOLIM   WSQOP  ***
  401  402   0.050          0.0060  0.4000   0.500
  701  702   0.050          0.0060  0.4000   0.500
  601  602   0.050          0.0060  0.4000   0.500
  END QUAL-INPUT

  QUAL-PROPS
    #    #<--QUALID-->    QTID  QSD VPFW  QSO  VQO   ***
  401  402         NH4     LBS    1    0    1    0
  701  702         NH4     LBS    1    0    1    0
  601  602         NH4     LBS    1    0    1    0
  END QUAL-PROPS

  QUAL-INPUT
    #    #     SQO   POTFW   ACQOP  SQOLIM   WSQOP  ***
  401  402   0.020     0.1  0.0010  0.1200   0.500
  701  702   0.020     0.1  0.0010  0.1200   0.500
  601  602   0.020     0.1  0.0010  0.1200   0.500
  END QUAL-INPUT

  QUAL-PROPS
    #    #<--QUALID-->    QTID  QSD VPFW  QSO  VQO   ***
  401  402         PO4     LBS    1    0    1    0
  701  702         PO4     LBS    1    0    1    0
  601  602         PO4     LBS    1    0    1    0
  END QUAL-PROPS

  QUAL-INPUT
    #    #     SQO   POTFW   ACQOP  SQOLIM   WSQOP  ***
  401        0.010     1.2  0.0006  0.0090   0.500
  402        0.010     1.0  0.0004  0.0090   0.500
```

```
  701        0.010     1.2  0.0006  0.0090   0.500
  702        0.010     1.0  0.0004  0.0090   0.500
  601        0.010     1.2  0.0006  0.0090   0.500
  602        0.010     1.0  0.0004  0.0090   0.500
  END QUAL-INPUT

  QUAL-PROPS
    #    #<--QUALID-->    QTID  QSD VPFW  QSO  VQO  ***
  401  402         BOD     LBS    0    0    1    0
  701  702         BOD     LBS    0    0    1    0
  601  602         BOD     LBS    0    0    1    0
  END QUAL-PROPS

  QUAL-INPUT
    #    #     SQO   POTFW   ACQOP  SQOLIM   WSQOP  ***
  401  402   1.900          0.3600  9.0000   0.500
  701  702   1.900          0.3600  9.0000   0.500
  601  602   1.900          0.3600  9.0000   0.500
  END QUAL-INPUT

END IMPLND

RCHRES
  ACTIVITY
    RCHRES  Active Sections (1=Active; 0=Inactive)           ***
    # -  # HYFG ADFG CNFG HTFG SDFG GQFG OXFG NUFG PKFG PHFG ***
    1    9    1    1    0    1    1    0    1    1    1    0
  END ACTIVITY

  PRINT-INFO
    RCHRES  Print-flags                                                ***
    # -  # HYDR ADCA CONS HEAT  SED  GQL OXRX NUTR PLNK PHCB PIVL  PYR ***
    1    9    5    6         6    5         5    5    5             12
  END PRINT-INFO

  GEN-INFO
    RCHRES<-------Name------->Nexit   Unit Systems   Printer      ***
    # -  #                          User t-series  Engl Metr LKFG ***
                                           in  out               ***
    1     UPR WEST BR             1    1    1    1   90    0    0
    2     LWR WBR-KENNETT GAGE    2    1    1    1   90    0    0
    3     EAST BR-CONFL WBR       2    1    1    1   90    0    0
    4     MS-ASHLAND              2    1    1    1   90    0    0
    5     ASHLAND-WOODDALE        1    1    1    1   90    0    0
    6     BURROUGHS RUN           1    1    1    1   90    0    0
    7     HOOPES RESERVOIR        1    1    1    1   90    0    0
    8     WOODDALE-STANTON        4    1    1    1   90    0    0
    9     STANTON-WHITE CLAY      1    1    1    1   90    0    0
  END GEN-INFO

**** HYDRAULICS

  HYDR-PARM1
    RCHRES  VC A1 A2 A3  ODFVFG for each *** ODGTFG for each     FUNCT  for each
    # -  #  FG FG FG FG  possible   exit *** possible   exit     possible   exit
    1        0  1  1  1    4  0  0  0  0       0  0  0  0  0       1  1  1  1  1
    2    4   0  1  1  1    4  0  0  0  0       0  2  0  0  0       1  1  1  1  1
    5    7   0  1  1  1    4  0  0  0  0       0  0  0  0  0       1  1  1  1  1
    8        0  1  1  1    4  0  0  0  0       0  2  3  4  0       1  1  1  1  1
    9        0  1  1  1    4  0  0  0  0       0  0  0  0  0       1  1  1  1  1
  END HYDR-PARM1

  HYDR-PARM2
    RCHRES    FTABNO       LEN     DELTH     STCOR        KS      DB50  ***
    # -  #             (miles)      (ft)      (ft)                (in)  ***
    1              1      5.00     160.0       0.0       0.5      0.01
    2              2      4.90      70.0       0.0       0.5      0.01
    3              3      7.20     170.0       0.0       0.5      0.01
    4              4      3.40      50.0       0.0       0.5      0.01
    5              5      5.10      60.0       0.0       0.5      0.01
    6              6      5.00     220.0       0.0       0.5      0.01
    7              7      1.70       0.0       0.0       0.5      0.01
    8              8      4.30      79.5       0.0       0.5      0.01
    9              9      0.84       0.5       0.0       0.5      0.01
  END HYDR-PARM2

  HYDR-INIT
    RCHRES       VOL ***   Initial value of COLIND      Initial value  of OUTDGT
    # -  #     ac-ft ***   for each exit                for each exit (ft3)
    1           2.10       4.0  0.0  0.0  0.0  0.0       0.0  0.0  0.0  0.0  0.0
    2           6.80       4.0  0.0  0.0  0.0  0.0       0.0 .001  0.0  0.0  0.0
    3           3.10       4.0  0.0  0.0  0.0  0.0       0.0  0.0  0.0  0.0  0.0
    4           5.70       4.0  0.0  0.0  0.0  0.0       0.0  3.1  0.0  0.0  0.0
    5          11.80       4.0  0.0  0.0  0.0  0.0       0.0  0.0  0.0  0.0  0.0
    6           1.30       4.0  0.0  0.0  0.0  0.0       0.0  0.0  0.0  0.0  0.0
    7   ***  5000.00       4.0  0.0  0.0  0.0  0.0       0.0  0.0  0.0  0.0  0.0
    8           8.00       4.0  0.0  0.0  0.0  0.0       0.0  0.0  0.0  0.0  0.0
    9           7.00       4.0  0.0  0.0  0.0  0.0       0.0  0.0  0.0  0.0  0.0
  END HYDR-INIT

  HT-BED-FLAGS
RCHRES *** BDFG TGFG TSTP
```

```
    1    9    1    3
  END HT-BED-FLAGS

  HEAT-PARM
RCHRES ***      ELEV     ELDAT    CFSAEX    KATRAD     KCOND     KEVAP
    1    7      200.     -440.      0.50       9.4      10.0       2.2
    8    9       40.      -35.      0.50       9.4      10.0       2.2
  END HEAT-PARM

  HT-BED-PARM
RCHRES ***    MUDDEP     TGRND      KMUD     KGRND
    1    9      0.01       61.       80       0.0
  END HT-BED-PARM

  MON-HT-TGRND
RCHRES ***  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
    1    9 39.0 40.0 44.0 51.0 58.0 64.0 69.0 70.0 66.0 60.0 51.0 44.0
  END MON-HT-TGRND

  HEAT-INIT
RCHRES ***        TW    AIRTMP
    1    9       59.       50.
  END HEAT-INIT

  SANDFG
RCHRES *** SNDFG
    1    9    3
  END SANDFG

  SED-GENPARM
RCHRES ***    BEDWID    BEDWRN       POR
    1    9       25.        6.       0.7
  END SED-GENPARM

  SAND-PM
RCHRES ***         D         W       RHO     KSAND    EXPSND
    1    9      .005       0.1       2.5      0.10      3.92
  END SAND-PM

  SILT-CLAY-PM
RCHRES ***         D         W       RHO     TAUCD     TAUCS         M
    1        0.00040    0.0003       2.2      0.13      0.50      0.90
    2    3   0.00040    0.0003       2.2      0.12      0.45      0.90
    4        0.00040    0.0003       2.2      0.15      0.58      0.90
    5        0.00040    0.0003       2.2      0.15      0.55      0.90
    6    7   0.00040    0.0003       2.2      0.16      0.60      0.90
    8    9   0.00040    0.0003       2.2      0.18      0.73      0.90
  END SILT-CLAY-PM

  SILT-CLAY-PM
RCHRES ***         D         W       RHO     TAUCD     TAUCS         M
    1        0.00010   0.00001       2.0      0.11      0.45      0.90
    2    3   0.00010   0.00001       2.0      0.10      0.40      0.90
    4        0.00010   0.00001       2.0      0.13      0.53      0.90
    5        0.00010   0.00001       2.0      0.13      0.50      0.90
    6    7   0.00010   0.00001       2.0      0.14      0.55      0.90
    8    9   0.00010   0.00001       2.0      0.16      0.68      0.90
  END SILT-CLAY-PM

  SSED-INIT
RCHRES ***     SSED1     SSED2     SSED3
    1    9        1.       25.       25.
  END SSED-INIT

  BED-INIT
RCHRES ***    BEDDEP    SANDFR    SILTFR    CLAYFR
    1    9        3.       .70       .20       .10
  END BED-INIT

  BENTH-FLAG
*** RCHRES BENF
    1    9    1
  END BENTH-FLAG

  SCOUR-PARMS
RCHRES ***    SCRVEL    SCRMUL
    1    9        3.         2
  END SCOUR-PARMS

  OX-FLAGS
*** RCHRES REAM
    1    9    3
  END OX-FLAGS

  OX-GENPARM
RCHRES ***    KBOD20     TCBOD    KODSET    SUPSAT
***    1    9      .004     1.047      .021      1.25
    1    9      .010     1.050      .020      1.25
***    1    3      .025     1.050      .200      1.25
***    4    5      .015     1.050      .200      1.25
***    6    7      .025     1.050      .200      1.25
***   8   9    .015    1.050     .200     1.25
```

```
  END OX-GENPARM

  OX-BENPARM
RCHRES ***     BENOD     TCBEN     EXPOD    BRBOD1    BRBOD2    EXPREL
    1    9       10.       1.1       1.2       10.       15.       2.5
 END OX-BENPARM

  OX-REAPARM
RCHRES ***    TCGINV      REAK    EXPRED     EXPREV
    1    9     1.024      .726    -1.673       .970
  END OX-REAPARM

  OX-INIT
RCHRES ***       DOX       BOD     SATDO
    1    9      11.3      2.92      12.0
  END OX-INIT
**** NUTRIENTS ****

  NUT-FLAGS
    RCHRES  TAM  NO2  PO4  AMV  DEN ADNH ADPO PHFG ***
    # -  #                                         ***
    1    9    1    0    1    0    1    1    1    2
  END NUT-FLAGS

  NUT-NITDENIT
    RCHRES    KTAM20    KNO220     TCNIT    KNO320     TCDEN    DENOXT ***
    # -  #       /hr       /hr                 /hr                 mg/l ***
***    1    9       .05      .050     1.045      .005      1.04        1.
    1    9       .07      .050     1.045      .005      1.04        1.
  END NUT-NITDENIT

  NUT-BEDCONC
    RCHRES       Bed concentrations of NH4 & PO4 (mg/kg)               ***
    # -  #  NH4-sand  NH4-silt  NH4-clay  PO4-sand  PO4-silt  PO4-clay ***
    1    9        1.       30.       50.       90.      700.      900.
  END NUT-BEDCONC

  NUT-ADSPARM
    RCHRES       Partition coefficients for NH4 AND PO4  (ml/g)        ***
    # -  #  NH4-sand  NH4-silt  NH4-clay  PO4-sand  PO4-silt  PO4-clay ***
    1    9       10.      700.      900.      600.    15000.    18000.
  END NUT-ADSPARM

  NUT-DINIT
    RCHRES       NO3       TAM       NO2       PO4        PH ***
    # -  #      mg/l      mg/l      mg/l      mg/l           ***
    1    9       2.0      .055                .033        7.
  END NUT-DINIT

  NUT-ADSINIT
    RCHRES        Initial suspended NH4 and PO4 concentrations (mg/kg) ***
    # -  #  NH4-sand  NH4-silt  NH4-clay  PO4-sand  PO4-silt  PO4-clay ***
    1    9       0.1       0.3       0.5       0.1       0.5       0.8
  END NUT-ADSINIT
**** PLANKTON ****

  PLNK-FLAGS
    RCHRES PHYF ZOOF BALF SDLT AMRF DECF NSFG ZFOO ***
    # -  #                                         ***
    1    9    1    0    1    0    0    1    1    2
  END PLNK-FLAGS

  PLNK-PARM1
    RCHRES    RATCLP    NONREF    LITSED     ALNPR      EXTB     MALGR ***
    # -  #                                             /ft       /hr ***
***    1    9       .60        .5        0.       0.8       .20      .200
    1              .60        .5        0.       0.6       .20      .200
    2              .60        .5        0.       0.5       .20      .200
    3              .60        .5        0.       0.6       .20      .200
    4    5       .60        .5        0.       0.5       .20      .200
    6    7       .60        .5        0.       0.7       .20      .200
    8    9       .60        .5        0.       0.5       .20      .200
  END PLNK-PARM1

  PLNK-PARM2
    RCHRES *** CMMLT      CMMN     CMMNP      CMMP    TALGRH    TALGRL    TALGRM
    # -  # ***ly/min      mg/l      mg/l      mg/l     deg F     deg F     deg F
    1    9       .03      .045      .029      .015       95.       32.       55.
  END PLNK-PARM2

  PLNK-PARM3
    RCHRES     ALR20      ALDH      ALDL     OXALD     NALDH     PALDH ***
    # -  #       /hr       /hr       /hr       /hr      mg/l      mg/l ***
    1    9      .045      .010      .001       .03      .015      .001
  END PLNK-PARM3

  PHYTO-PARM
    RCHRES      SEED    MXSTAY      OREF    CLALDH    PHYSET    REFSET ***
    # -  #      mg/l      mg/l                ug/l                     ***
    1    9        .4        .8       20.       50.      .012      .010
  END PHYTO-PARM
```

```
  PLNK-INIT
    RCHRES     PHYTO       ZOO     BENAL       ORN       ORP       ORC ***
    # -  #      mg/l     org/l     mg/m2      mg/l      mg/l      mg/l ***
    1    9      .700       .03    1.0E-8        1.        .2        8.
  END PLNK-INIT

END RCHRES

FTABLES
  FTABLE      1
 ROWS COLS *** West Br., to Chandler’s Mill Rd.
   15    4
     DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
      (FT)   (ACRES)   (AC-FT)     (CFS)     (MIN) ***
      0.00       0.0       0.0       0.0        0.
      0.33      10.5       3.4       6.0      408.
      0.67      11.3       7.0      19.3      264.
      1.00      12.1      10.9      38.3      207.
      1.33      12.9      15.1      62.8      174.
      1.67      13.7      19.5      92.4      153.
      2.00      14.5      24.2     127.2      138.
      2.67      16.2      34.5     212.1      118.
      3.33      17.8      45.8     318.2      104.
      4.00      19.4      58.2     446.0       95.
      5.33      51.7     105.6     836.0       92.
      6.67      84.0     196.1     1368.      104.
      8.00     116.4     329.7     2067.      116.
      9.33     148.7     506.4     2957.      124.
     10.67     181.0     726.2     4057.      130.
  END FTABLE  1

  FTABLE      2
 ROWS COLS *** West Br., to confluence w/ East Br.
   15    4
     DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
      (FT)   (ACRES)   (AC-FT)     (CFS)     (MIN) ***
      0.00       0.0       0.0       0.0        0.
      0.42      14.7       5.9       7.6      565.
      0.83      15.8      12.3      24.4      366.
      1.25      16.9      19.1      48.6      286.
      1.67      18.0      26.4      79.5      241.
      2.08      19.1      34.1     117.1      212.
      2.50      20.2      42.3     161.1      191.
      3.33      22.4      60.1     268.5      162.
      4.17      24.5      79.6     402.3      144.
      5.00      26.7     101.0     563.4      130.
      6.67      66.3     178.5     1051.      123.
      8.33     105.9     322.0     1714.      136.
     10.00     145.5     531.6     2582.      149.
     11.67     185.1     807.1     3684.      159.
     13.33     224.7    1148.6     5043.      165.
  END FTABLE  2

  FTABLE      3
 ROWS COLS *** East Br., to Kennett gage
   15    4
     DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
      (FT)   (ACRES)   (AC-FT)     (CFS)     (MIN) ***
      0.00       0.0       0.0       0.0        0.
      0.38      11.4       4.2       4.9      628.
      0.77      12.4       8.8      15.5      409.
      1.15      13.3      13.7      30.8      322.
      1.53      14.3      19.0      50.4      273.
      1.92      15.2      24.6      74.0      241.
      2.30      16.1      30.6     101.8      218.
      3.07      18.0      43.7     169.6      187.
      3.83      19.9      58.3     254.3      166.
      4.60      21.8      74.3     356.6      151.
      6.13      66.4     141.9     675.9      152.
      7.67     111.0     278.0     1123.      180.
      9.20     155.6     482.4     1728.      203.
     10.73     200.2     755.3     2513.      218.
     12.27     244.8    1096.5     3502.      227.
  END FTABLE  3

  FTABLE      4
 ROWS COLS *** MStem, Kennett Gage to Barley Mill Rd.(Ashland)
   15    4
     DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
      (FT)   (ACRES)   (AC-FT)     (CFS)     (MIN) ***
      0.00       0.0       0.0       0.0        0.
      0.58      20.2      11.6      29.4      287.
      1.17      20.5      23.5      93.1      183.
      1.75      20.9      35.6     182.3      142.
      2.33      21.3      47.9     293.5      119.
      2.92      21.7      60.5     424.6      103.
      3.50      22.0      73.2     573.9       93.
      4.67      22.8      99.4     923.4       78.
      5.83      23.6     126.4     1335.       69.
      7.00      24.3     154.3     1806.       62.
      9.33      62.8     256.0     3082.       60.
     11.67     101.2     447.3     4768.       68.
```

```
    14.00     139.7     728.4     6946.       76.
    16.33     178.2    1099.3     9687.       82.
    18.67     216.6    1559.9    13053.       87.
 END FTABLE  4

 FTABLE      5
ROWS COLS *** MStem,Barley Mill Rd to Wooddale Gage
  15    4
    DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
     (FT)   (ACRES)   (AC-FT)     (CFS)     (MIN) ***
     0.00       0.0       0.0       0.0        0.
     0.60      31.5      18.7      33.2      409.
     1.20      32.1      37.8     105.1      261.
     1.80      32.8      57.3     206.0      202.
     2.40      33.4      77.1     331.9      169.
     3.00      34.0      97.4     480.3      147.
     3.60      34.6     117.9     649.7      132.
     4.80      35.9     160.2     1046.      111.
     6.00      37.1     204.0     1515.       98.
     7.20      38.3     249.3     2051.       88.
     9.60      87.8     400.6     3492.       83.
    12.00     137.2     670.6     5347.       91.
    14.40     186.7    1059.3     7675.      100.
    16.80     236.1    1566.7    10526.      108.
    19.20     285.6    2192.8    13948.      114.
 END FTABLE  5

 FTABLE      6
ROWS COLS *** Burroughs Run
  15    4
    DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
     (FT)   (ACRES)   (AC-FT)     (CFS)     (MIN) ***
     0.00       0.0       0.0       0.0        0.
     0.49       9.7       4.6      12.0      280.
     0.98      10.3       9.5      37.9      183.
     1.48      10.9      14.8      74.5      144.
     1.97      11.5      20.3     120.8      122.
     2.46      12.1      26.1     175.9      108.
     2.95      12.7      32.2     239.8       97.
     3.93      13.9      45.3     393.1       84.
     4.92      15.2      59.6     580.4       75.
     5.90      16.4      75.1     802.3       68.
     7.87      40.2     130.7     1475.       64.
     9.83      64.0     233.2     2383.       71.
    11.80      87.9     382.6     3571.       78.
    13.77     111.7     578.9     5076.       83.
    15.73     135.6     822.0     6929.       86.
 END FTABLE  6

 FTABLE      7
ROWS COLS *** Hoopes Reservoir
  12    4
    DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
     (FT)   (ACRES)   (AC-FT)     (CFS)     (MIN) ***
     0.00       0.0       0.0       0.0        0.
     12.5       3.0      31.0       0.0        0.
     22.5       5.0     107.0       0.0        0.
     32.5      10.0     276.0       0.0        0.
     42.5      19.0     583.0       0.0        0.
     52.5      33.0     982.0       0.0        0.
     62.5      52.0    1534.0       0.0        0.
     72.5      90.0    2240.0       0.0        0.
     82.5     105.0    3284.0       0.0        0.
     92.5     150.0    4604.0       0.0        0.
    102.5     200.0    6267.0       0.0        0.
    104.5     210.0    6598.0      58.4        0.
 END FTABLE  7

 FTABLE      8
ROWS COLS *** MStem, Wooddale Gage to Stanton Gage
  15    4
    DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
     (FT)   (ACRES)   (AC-FT)     (CFS)     (MIN) ***
     0.00       0.0       0.0       0.0        0.
     0.72      37.7      27.6      81.6      246.
     1.45      36.8      54.7     249.5      159.
     2.17      36.0      81.1     472.2      125.
     2.90      35.1     106.8     734.7      106.
     3.62      34.2     131.9     1027.       93.
     4.35      33.4     156.4     1341.       85.
     5.80      31.6     203.6     2012.       73.
     7.25      29.9     248.1     2712.       66.
     8.70      28.1     290.2     3418.       62.
    11.60     128.9     517.9     5292.       71.
    14.50     229.7    1037.9     7996.       94.
    17.40     330.4    1850.1    11848.      113.
    20.30     431.2    2954.5    17115.      125.
    23.20     532.0    4351.1    24033.      131.
 END FTABLE  8

 FTABLE      9
ROWS COLS *** MStem, Stanton to confl w/White Clay
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```
   15    4
     DEPTH      AREA    VOLUME     DISCH  FLO-THRU ***
      (FT)   (ACRES)   (AC-FT)     (CFS)     (MIN) ***
      0.00       0.0       0.0       0.0        0.
      0.83       6.6       5.5      16.5      244.
      1.67       6.4      11.0      50.4      158.
      2.50       6.3      16.3      95.5      124.
      3.33       6.2      21.5     148.6      105.
      4.17       6.0      26.6     207.9       93.
      5.00       5.9      31.6     271.7       84.
      6.67       5.6      41.2     408.6       73.
      8.33       5.4      50.3     552.5       66.
     10.00       5.1      59.1     698.3       61.
     13.33      39.0     132.6     1113.       86.
     16.67      73.0     319.3     1802.      129.
     20.00     106.9     619.1     2894.      155.
     23.33     140.8    1032.0     4494.      167.
     26.67     174.8    1558.0     6697.      169.
  END FTABLE  9
END FTABLES

COPY
  TIMESERIES
    # -  #  NPT  NMN ***
   10  400        18
  END TIMESERIES
END COPY

EXT SOURCES
<-Volume-> <Member> SsysSgap<--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>   # <Name> # tem strg<-factor->strg <Name>   #   #        <Name> # #  ***
*** Meteorological data
WDM1    76 PREC   0 ENGL          0.90     PERLND 702 711 EXTNL  PREC   1 1
WDM1    76 PREC   0 ENGL          0.87     PERLND 402 411 EXTNL  PREC   1 1
WDM1    76 PREC   0 ENGL          0.85     PERLND 602 611 EXTNL  PREC   1 1
WDM1   160 NO3X   0 METR           1.0     PERLND 402 611 EXTNL  NIADCN 1 1
WDM1   161 NH3X   0 METR           1.0     PERLND 402 611 EXTNL  NIADCN 2 1
WDM1    76 PREC   0 ENGL        17509.     COPY   200     INPUT  MEAN   4 1
WDM1    76 PREC   0 ENGL        28678.     COPY   300     INPUT  MEAN   4 1
WDM1    76 PREC   0 ENGL        31121.     COPY   400     INPUT  MEAN   4 1
WDM1    52 ATMP   0 ENGL           1.0     PERLND 702 711 EXTNL  GATMP  1 1
WDM1    52 ATMP   0 ENGL           1.0     PERLND 402 411 EXTNL  GATMP  1 1
WDM1    50 ATMP   0 ENGL           1.0     PERLND 602 611 EXTNL  GATMP  1 1
WDM1    20 PETX   0 ENGL           1.1     PERLND 402 711 EXTNL  PETINP 1 1
WDM1    45 DWPT   0 ENGL           1.0     PERLND 402 711 EXTNL  DTMPG  1 1
WDM1    30 WIND   0 ENGL           1.0     PERLND 402 711 EXTNL  WINMOV 1 1
WDM1    10 SOLR   0 ENGL           1.0     PERLND 402 711 EXTNL  SOLRAD 1 1
WDM1    76 PREC   0 ENGL          0.90     IMPLND 701 702 EXTNL  PREC   1 1
WDM1    76 PREC   0 ENGL          0.87     IMPLND 401 402 EXTNL  PREC   1 1
WDM1    76 PREC   0 ENGL          0.85     IMPLND 601 602 EXTNL  PREC   1 1
WDM1    52 ATMP   0 ENGL           1.0     IMPLND 701 702 EXTNL  GATMP  1 1
WDM1    52 ATMP   0 ENGL           1.0     IMPLND 401 402 EXTNL  GATMP  1 1
WDM1    50 ATMP   0 ENGL           1.0     IMPLND 601 602 EXTNL  GATMP  1 1
WDM1    20 PETX   0 ENGL           1.1     IMPLND 401 702 EXTNL  PETINP 1 1
WDM1    45 DWPT   0 ENGL           1.0     IMPLND 401 702 EXTNL  DTMPG  1 1
WDM1    30 WIND   0 ENGL           1.0     IMPLND 401 702 EXTNL  WINMOV 1 1
WDM1    10 SOLR   0 ENGL           1.0     IMPLND 401 702 EXTNL  SOLRAD 1 1
WDM1    76 PREC   0 ENGL          0.90     RCHRES   1   3 EXTNL  PREC   1 1
WDM1    76 PREC   0 ENGL          0.87     RCHRES   4   7 EXTNL  PREC   1 1
WDM1    76 PREC   0 ENGL          0.85     RCHRES   8   9 EXTNL  PREC   1 1
WDM1   160 NO3X   0 METR           1.0     RCHRES   1   9 EXTNL  NUADCN 1 1
WDM1   161 NH3X   0 METR           1.0     RCHRES   1   9 EXTNL  NUADCN 2 1
WDM1    52 ATMP   0 ENGL           1.0     RCHRES   1   3 EXTNL  GATMP  1 1
WDM1    52 ATMP   0 ENGL           1.0     RCHRES   4   7 EXTNL  GATMP  1 1
WDM1    50 ATMP   0 ENGL           1.0     RCHRES   8   9 EXTNL  GATMP  1 1
WDM1    45 DWPT   0 ENGL           1.0     RCHRES   1   9 EXTNL  DEWTMP 1 1
WDM1    40 COVR   0 ENGL           1.0     RCHRES   1   9 EXTNL  CLOUD  1 1
WDM1    30 WIND   0 ENGL           1.0     RCHRES   1   9 EXTNL  WIND   1 1
WDM1    20 PETX   0 ENGL           1.1     RCHRES   1   9 EXTNL  POTEV  1 1
WDM1    10 SOLR   0 ENGL           1.0     RCHRES   1   9 EXTNL  SOLRAD 1 1
*** Point source Discharges to Red Clay
***New Bolton Center
WDM1   300 PTSQ   0 ENGL           1.0     RCHRES   1     EXTNL  IVOL   1 1
WDM1   301 TSSX   0 ENGL           1.0     RCHRES   1     INFLOW ISED   3 1
WDM1   302 BODX   0 ENGL           1.0     RCHRES   1     INFLOW OXIF   2 1
WDM1   303 NH3X   0 ENGL           1.0     RCHRES   1     INFLOW NUIF1  2 1
WDM1   304 NO3X   0 ENGL           1.0     RCHRES   1     INFLOW NUIF1  1 1
WDM1   305 NO2X   0 ENGL           1.0     RCHRES   1     INFLOW NUIF1  3 1
WDM1   306 PO4X   0 ENGL           1.0     RCHRES   1     INFLOW NUIF1  4 1
WDM1   308 HEAT   0 ENGL           1.0     RCHRES   1     INFLOW IHEAT  1 1
*** Sunny Dell Foods PA-001
WDM1   310 PTSQ   0 ENGL           1.0     RCHRES   3     EXTNL  IVOL   1 1
WDM1   311 TSSX   0 ENGL           1.0     RCHRES   3     INFLOW ISED   3 1
WDM1   312 BODX   0 ENGL           1.0     RCHRES   3     INFLOW OXIF   2 1
WDM1   313 NH3X   0 ENGL           1.0     RCHRES   3     INFLOW NUIF1  2 1
WDM1   314 NO3X   0 ENGL           1.0     RCHRES   3     INFLOW NUIF1  1 1
WDM1   315 NO2X   0 ENGL           1.0     RCHRES   3     INFLOW NUIF1  3 1
WDM1   316 PO4X   0 ENGL           1.0     RCHRES   3     INFLOW NUIF1  4 1
WDM1   318 HEAT   0 ENGL           1.0     RCHRES   3     INFLOW IHEAT  1 1
*** Sunny Dell Foods PA-003
WDM1   320 PTSQ   0 ENGL           1.0     RCHRES   3     EXTNL  IVOL   1 1
WDM1   321 TSSX   0 ENGL           1.0     RCHRES   3     INFLOW ISED   3 1
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WDM1   322 BODX   0 ENGL           1.0     RCHRES   3     INFLOW OXIF   2 1
WDM1   323 NH3X   0 ENGL           1.0     RCHRES   3     INFLOW NUIF1  2 1
WDM1   324 NO3X   0 ENGL           1.0     RCHRES   3     INFLOW NUIF1  1 1
WDM1   325 NO2X   0 ENGL           1.0     RCHRES   3     INFLOW NUIF1  3 1
WDM1   326 PO4X   0 ENGL           1.0     RCHRES   3     INFLOW NUIF1  4 1
WDM1   328 HEAT   0 ENGL           1.0     RCHRES   3     INFLOW IHEAT  1 1
*** East Marlborough Twp STP
WDM1   330 PTSQ   0 ENGL           1.0     RCHRES   3     EXTNL  IVOL   1 1
WDM1   331 TSSX   0 ENGL           1.0     RCHRES   3     INFLOW ISED   3 1
WDM1   332 BODX   0 ENGL           1.0     RCHRES   3     INFLOW OXIF   2 1
WDM1   333 NH3X   0 ENGL           1.0     RCHRES   3     INFLOW NUIF1  2 1
WDM1   334 NO3X   0 ENGL           1.0     RCHRES   3     INFLOW NUIF1  1 1
WDM1   335 NO2X   0 ENGL           1.0     RCHRES   3     INFLOW NUIF1  3 1
WDM1   336 PO4X   0 ENGL           1.0     RCHRES   3     INFLOW NUIF1  4 1
WDM1   338 HEAT   0 ENGL           1.0     RCHRES   3     INFLOW IHEAT  1 1
*** NVF Kennett Square
WDM1   340 PTSQ   0 ENGL           1.0     RCHRES   1     EXTNL  IVOL   1 1
WDM1   341 TSSX   0 ENGL           1.0     RCHRES   1     INFLOW ISED   3 1
WDM1   342 BODX   0 ENGL           1.0     RCHRES   1     INFLOW OXIF   2 1
WDM1   343 NH3X   0 ENGL           1.0     RCHRES   1     INFLOW NUIF1  2 1
WDM1   344 NO3X   0 ENGL           1.0     RCHRES   1     INFLOW NUIF1  1 1
WDM1   345 NO2X   0 ENGL           1.0     RCHRES   1     INFLOW NUIF1  3 1
WDM1   346 PO4X   0 ENGL           1.0     RCHRES   1     INFLOW NUIF1  4 1
WDM1   348 HEAT   0 ENGL           1.0     RCHRES   1     INFLOW IHEAT  1 1
*** Kennett Square Borough STP
WDM1   350 PTSQ   0 ENGL           1.0     RCHRES   2     EXTNL  IVOL   1 1
WDM1   351 TSSX   0 ENGL           1.0     RCHRES   2     INFLOW ISED   3 1
WDM1   352 BODX   0 ENGL           1.0     RCHRES   2     INFLOW OXIF   2 1
WDM1   353 NH3X   0 ENGL           1.0     RCHRES   2     INFLOW NUIF1  2 1
WDM1   354 NO3X   0 ENGL           1.0     RCHRES   2     INFLOW NUIF1  1 1
WDM1   355 NO2X   0 ENGL           1.0     RCHRES   2     INFLOW NUIF1  3 1
WDM1   356 PO4X   0 ENGL           1.0     RCHRES   2     INFLOW NUIF1  4 1
WDM1   358 HEAT   0 ENGL           1.0     RCHRES   2     INFLOW IHEAT  1 1
*** D’Ambro
WDM1   360 PTSQ   0 ENGL           1.0     RCHRES   6     EXTNL  IVOL   1 1
WDM1   361 TSSX   0 ENGL           1.0     RCHRES   6     INFLOW ISED   3 1
WDM1   362 BODX   0 ENGL           1.0     RCHRES   6     INFLOW OXIF   2 1
WDM1   363 NH3X   0 ENGL           1.0     RCHRES   6     INFLOW NUIF1  2 1
WDM1   364 NO3X   0 ENGL           1.0     RCHRES   6     INFLOW NUIF1  1 1
WDM1   365 NO2X   0 ENGL           1.0     RCHRES   6     INFLOW NUIF1  3 1
WDM1   366 PO4X   0 ENGL           1.0     RCHRES   6     INFLOW NUIF1  4 1
WDM1   368 HEAT   0 ENGL           1.0     RCHRES   6     INFLOW IHEAT  1 1
*** NVF Yorklyn
WDM1   370 PTSQ   0 ENGL           1.0     RCHRES   4     EXTNL  IVOL   1 1
WDM1   371 TSSX   0 ENGL           1.0     RCHRES   4     INFLOW ISED   3 1
WDM1   372 BODX   0 ENGL           1.0     RCHRES   4     INFLOW OXIF   2 1
WDM1   373 NH3X   0 ENGL           1.0     RCHRES   4     INFLOW NUIF1  2 1
WDM1   374 NO3X   0 ENGL           1.0     RCHRES   4     INFLOW NUIF1  1 1
WDM1   375 NO2X   0 ENGL           1.0     RCHRES   4     INFLOW NUIF1  3 1
WDM1   376 PO4X   0 ENGL           1.0     RCHRES   4     INFLOW NUIF1  4 1
WDM1   378 HEAT   0 ENGL           1.0     RCHRES   4     INFLOW IHEAT  1 1
*** Greenville County Club
WDM1   380 PTSQ   0 ENGL           1.0     RCHRES   5     EXTNL  IVOL   1 1
WDM1   381 TSSX   0 ENGL           1.0     RCHRES   5     INFLOW ISED   3 1
WDM1   382 BODX   0 ENGL           1.0     RCHRES   5     INFLOW OXIF   2 1
WDM1   383 NH3X   0 ENGL           1.0     RCHRES   5     INFLOW NUIF1  2 1
WDM1   384 NO3X   0 ENGL           1.0     RCHRES   5     INFLOW NUIF1  1 1
WDM1   385 NO2X   0 ENGL           1.0     RCHRES   5     INFLOW NUIF1  3 1
WDM1   386 PO4X   0 ENGL           1.0     RCHRES   5     INFLOW NUIF1  4 1
WDM1   388 HEAT   0 ENGL           1.0     RCHRES   5     INFLOW IHEAT  1 1
*** Hercules Inc.
WDM1   390 PTSQ   0 ENGL           1.0     RCHRES   8     EXTNL  IVOL   1 1
WDM1   391 TSSX   0 ENGL           1.0     RCHRES   8     INFLOW ISED   3 1
WDM1   392 BODX   0 ENGL           1.0     RCHRES   8     INFLOW OXIF   2 1
WDM1   393 NH3X   0 ENGL           1.0     RCHRES   8     INFLOW NUIF1  2 1
WDM1   394 NO3X   0 ENGL           1.0     RCHRES   8     INFLOW NUIF1  1 1
WDM1   395 NO2X   0 ENGL           1.0     RCHRES   8     INFLOW NUIF1  3 1
WDM1   396 PO4X   0 ENGL           1.0     RCHRES   8     INFLOW NUIF1  4 1
WDM1   398 HEAT   0 ENGL           1.0     RCHRES   8     INFLOW IHEAT  1 1
*** Haveg/Ametek -003
WDM1   400 PTSQ   0 ENGL           1.0     RCHRES   8     EXTNL  IVOL   1 1
WDM1   401 TSSX   0 ENGL           1.0     RCHRES   8     INFLOW ISED   3 1
WDM1   402 BODX   0 ENGL           1.0     RCHRES   8     INFLOW OXIF   2 1
WDM1   403 NH3X   0 ENGL           1.0     RCHRES   8     INFLOW NUIF1  2 1
WDM1   404 NO3X   0 ENGL           1.0     RCHRES   8     INFLOW NUIF1  1 1
WDM1   405 NO2X   0 ENGL           1.0     RCHRES   8     INFLOW NUIF1  3 1
WDM1   406 PO4X   0 ENGL           1.0     RCHRES   8     INFLOW NUIF1  4 1
WDM1   408 HEAT   0 ENGL           1.0     RCHRES   8     INFLOW IHEAT  1 1
*** Haveg/Ammetek -001
WDM1   410 PTSQ   0 ENGL           1.0     RCHRES   8     EXTNL  IVOL   1 1
WDM1   411 TSSX   0 ENGL           1.0     RCHRES   8     INFLOW ISED   3 1
WDM1   412 BODX   0 ENGL           1.0     RCHRES   8     INFLOW OXIF   2 1
WDM1   413 NH3X   0 ENGL           1.0     RCHRES   8     INFLOW NUIF1  2 1
WDM1   414 NO3X   0 ENGL           1.0     RCHRES   8     INFLOW NUIF1  1 1
WDM1   415 NO2X   0 ENGL           1.0     RCHRES   8     INFLOW NUIF1  3 1
WDM1   416 PO4X   0 ENGL           1.0     RCHRES   8     INFLOW NUIF1  4 1
WDM1   418 HEAT   0 ENGL           1.0     RCHRES   8     INFLOW IHEAT  1 1
*** Center for Creative Arts
WDM1   420 PTSQ   0 ENGL           1.0     RCHRES   4     EXTNL  IVOL   1 1
WDM1   421 TSSX   0 ENGL           1.0     RCHRES   4     INFLOW ISED   3 1
WDM1   422 BODX   0 ENGL           1.0     RCHRES   4     INFLOW OXIF   2 1
WDM1   423 NH3X   0 ENGL           1.0     RCHRES   4     INFLOW NUIF1  2 1
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WDM1   424 NO3X   0 ENGL           1.0     RCHRES   4     INFLOW NUIF1  1 1
WDM1   425 NO2X   0 ENGL           1.0     RCHRES   4     INFLOW NUIF1  3 1
WDM1   426 PO4X   0 ENGL           1.0     RCHRES   4     INFLOW NUIF1  4 1
WDM1   428 HEAT   0 ENGL           1.0     RCHRES   4     INFLOW IHEAT  1 1
*** Withdrawals from Red Clay
*** NVF, Yorklyn
WDM1   200 WITH   0 ENGL           1.0SAME RCHRES   4     EXTNL  OUTDGT 2 1
*** Hercules Research Center, Wooddale
WDM1   210 WITH   0 ENGL           1.0SAME RCHRES   8     EXTNL  OUTDGT 2 1
*** Hercules Country Club, Wooddale
WDM1   220 WITH   0 ENGL           1.0SAME RCHRES   8     EXTNL  OUTDGT 3 1
*** Samuel Beard, Wilmington
WDM1   230 WITH   0 ENGL           1.0SAME RCHRES   8     EXTNL  OUTDGT 4 1
*** J.H. Thompson, New Garden
WDM1   240 WITH   0 ENGL           1.0SAME RCHRES   2     EXTNL  OUTDGT 2 1
*** Kennett Sq. Golf, Kennett Square
WDM1   250 WITH   0 ENGL           1.0SAME RCHRES   3     EXTNL  OUTDGT 2 1

END EXT SOURCES

EXT TARGETS
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Volume-> <Member> Tsys Aggr Amd ***
<Name>   x        <Name> x x<-factor->strg <Name>   x <Name>qf  tem strg strg***
***mult factor for rovol is 12/area
*** mult factor for others 1/area
RCHRES   2 OFLOW  OVOL   1  .000685362     WDM   1120 FLOW     ENGL      REPL
RCHRES   2 HYDR   O      1                 WDM   1129 FLOW     ENGL      REPL
COPY   200 OUTPUT MEAN   1  .000057113     WDM   1121 SURO     ENGL      REPL
COPY   200 OUTPUT MEAN   2  .000057113     WDM   1122 IFWO     ENGL      REPL
COPY   200 OUTPUT MEAN   3  .000057113     WDM   1123 AGWO     ENGL      REPL
COPY   200 OUTPUT MEAN   4  .000057113     WDM   1124 PREC     ENGL      REPL
COPY   200 OUTPUT MEAN   5  .000057113     WDM   1125 PETX     ENGL      REPL
COPY   200 OUTPUT MEAN   6  .000057113     WDM   1126 TAET     ENGL      REPL
COPY   200 OUTPUT MEAN   7  .000057113     WDM   1127 UZSX     ENGL      REPL
COPY   200 OUTPUT MEAN   8  .000057113     WDM   1128 LZSX     ENGL      REPL
RCHRES   5 ROFLOW ROVOL     .000418439     WDM   1110 FLOW     ENGL      REPL
RCHRES   5 HYDR   RO                       WDM   1119 FLOW     ENGL      REPL
COPY   300 OUTPUT MEAN   1  .000034870     WDM   1111 SURO     ENGL      REPL
COPY   300 OUTPUT MEAN   2  .000034870     WDM   1112 IFWO     ENGL      REPL
COPY   300 OUTPUT MEAN   3  .000034870     WDM   1113 AGWO     ENGL      REPL
COPY   300 OUTPUT MEAN   4  .000034870     WDM   1114 PREC     ENGL      REPL
COPY   300 OUTPUT MEAN   5  .000034870     WDM   1115 PETX     ENGL      REPL
COPY   300 OUTPUT MEAN   6  .000034870     WDM   1116 TAET     ENGL      REPL
COPY   300 OUTPUT MEAN   7  .000034870     WDM   1117 UZSX     ENGL      REPL
COPY   300 OUTPUT MEAN   8  .000034870     WDM   1118 LZSX     ENGL      REPL
*** total loads from pervious and impervious areas above Wooodale
COPY   300 OUTPUT MEAN  10  1.00000000     WDM   2100 SOSED    ENGL      REPL
COPY   300 OUTPUT MEAN  11  1.00000000     WDM   2125 PONO3    ENGL      REPL
COPY   300 OUTPUT MEAN  12  1.00000000     WDM   2126 PONH4    ENGL      REPL
COPY   300 OUTPUT MEAN  13  1.00000000     WDM   2127 POPHOS   ENGL      REPL
COPY   300 OUTPUT MEAN  14  1.00000000     WDM   2130 SOSLD    ENGL      REPL
COPY   300 OUTPUT MEAN  15  1.00000000     WDM   2135 IONO3    ENGL      REPL
COPY   300 OUTPUT MEAN  16  1.00000000     WDM   2136 IONH4    ENGL      REPL
COPY   300 OUTPUT MEAN  17  1.00000000     WDM   2137 IOPHOS   ENGL      REPL
*** output for Reach 8 Stanton
RCHRES   8 OFLOW  OVOL   1  .000373587     WDM   1100 FLOW     ENGL      REPL
RCHRES   8 HYDR   O      1                 WDM   1109 FLOW     ENGL      REPL
COPY   400 OUTPUT MEAN   1  .000031132     WDM   1101 SURO     ENGL      REPL
COPY   400 OUTPUT MEAN   2  .000031132     WDM   1102 IFWO     ENGL      REPL
COPY   400 OUTPUT MEAN   3  .000031132     WDM   1103 AGWO     ENGL      REPL
COPY   400 OUTPUT MEAN   4  .000031132     WDM   1104 PREC     ENGL      REPL
COPY   400 OUTPUT MEAN   5  .000031132     WDM   1105 PETX     ENGL      REPL
COPY   400 OUTPUT MEAN   6  .000031132     WDM   1106 TAET     ENGL      REPL
COPY   400 OUTPUT MEAN   7  .000031132     WDM   1107 UZSX     ENGL      REPL
COPY   400 OUTPUT MEAN   8  .000031132     WDM   1108 LZSX     ENGL      REPL
*** total loads from pervious and impervious areas above Stanton
COPY   400 OUTPUT MEAN  10  1.00000000     WDM   2200 SOSED    ENGL      REPL
COPY   400 OUTPUT MEAN  11  1.00000000     WDM   2225 PONO3    ENGL      REPL
COPY   400 OUTPUT MEAN  12  1.00000000     WDM   2226 PONH4    ENGL      REPL
COPY   400 OUTPUT MEAN  13  1.00000000     WDM   2227 POPHOS   ENGL      REPL
COPY   400 OUTPUT MEAN  14  1.00000000     WDM   2230 SOSLD    ENGL      REPL
COPY   400 OUTPUT MEAN  15  1.00000000     WDM   2235 IONO3    ENGL      REPL
COPY   400 OUTPUT MEAN  16  1.00000000     WDM   2236 IONH4    ENGL      REPL
COPY   400 OUTPUT MEAN  17  1.00000000     WDM   2237 IOPHOS   ENGL      REPL
***water temperature output
RCHRES   2 HTRCH  TW                       WDM   1520 WTEM     METR      REPL
RCHRES   5 HTRCH  TW                       WDM   1510 WTEM     METR      REPL
RCHRES   8 HTRCH  TW                       WDM   1500 WTEM     METR      REPL
*** suspended sediment concentration output
RCHRES   1 SEDTRN SSED   4                 WDM   1600 SEDC     METR      REPL
RCHRES   2 SEDTRN SSED   4                 WDM   1620 SEDC     METR      REPL
RCHRES   3 SEDTRN SSED   4                 WDM   1640 SEDC     METR      REPL
RCHRES   4 SEDTRN SSED   4                 WDM   1660 SEDC     METR      REPL
RCHRES   5 SEDTRN SSED   4                 WDM   1680 SEDC     METR      REPL
RCHRES   6 SEDTRN SSED   4                 WDM   1700 SEDC     METR      REPL
RCHRES   8 SEDTRN SSED   4                 WDM   1740 SEDC     METR      REPL
*** Water Quality
*** oxygen, bod, nutrients
RCHRES   1 OXRX   DOX                      WDM   1601 DOXX     METR      REPL
RCHRES   1 OXRX   BOD                   WDM   1602 BODX    METR     REPL
*** Dissolved NO3
RCHRES   1 NUTRX  DNUST  1              WDM   1603 NO3X    METR     REPL
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*** Dissolved NH3
RCHRES   1 NUTRX  DNUST  2                WDM   1604 NH4X     METR      REPL
*** Dissolved PO4
RCHRES   1 NUTRX  DNUST  4              WDM   1605 PO4X     METR      REPL
*** particulate ammonia and phosphate
COPY    11 OUTPUT MEAN   1    ***              WDM   1666 NH4P     METR      REPL
COPY    11 OUTPUT MEAN   2    ***              WDM   1667 PO4P     METR      REPL
*** organic nitrogen and chlorophyll-A
RCHRES   1 PLANK  PHYCLA 1                 WDM   1608 PHCA     METR      REPL
RCHRES   1 PLANK  PKST3  4                 WDM   1609 TORN     METR      REPL
RCHRES   2 OXRX   DOX                      WDM   1621 DOXX     METR      REPL
RCHRES   2 OXRX   BOD                      WDM   1622 BODX     METR      REPL
RCHRES   2 NUTRX  DNUST  1                 WDM   1623 NO3X     METR      REPL
RCHRES   2 NUTRX  DNUST  2                 WDM   1624 NH4X     METR      REPL
RCHRES   2 NUTRX  DNUST  4                 WDM   1625 PO4X     METR      REPL
COPY    10 OUTPUT MEAN   1                 WDM   1626 NH4P     METR      REPL
COPY    10 OUTPUT MEAN   2                 WDM   1627 PO4P     METR      REPL
RCHRES   2 PLANK  PHYCLA 1                 WDM   1628 PHCA     METR      REPL
RCHRES   2 PLANK  PKST3  4                 WDM   1629 TORN     METR      REPL
RCHRES   3 OXRX   DOX                      WDM   1641 DOXX     METR      REPL
RCHRES   3 OXRX   BOD                    WDM   1642 BODX     METR      REPL
RCHRES   3 NUTRX  DNUST  1                WDM   1643 NO3X     METR      REPL
RCHRES   3 NUTRX  DNUST  2                WDM   1644 NH4X     METR      REPL
RCHRES   3 NUTRX  DNUST  4              WDM   1645 PO4X     METR      REPL
COPY    11 OUTPUT MEAN   1                 WDM   1666 NH4P     METR      REPL
COPY    11 OUTPUT MEAN   2                 WDM   1667 PO4P     METR      REPL
RCHRES   3 PLANK  PHYCLA 1                 WDM   1648 PHCA     METR      REPL
RCHRES   3 PLANK  PKST3  4                 WDM   1649 TORN     METR      REPL
RCHRES   4 OXRX   DOX                      WDM   1661 DOXX     METR      REPL
RCHRES   4 OXRX   BOD                    WDM   1662 BODX     METR      REPL
RCHRES   4 NUTRX  DNUST  1                WDM   1663 NO3X     METR      REPL
RCHRES   4 NUTRX  DNUST  2                WDM   1664 NH4X     METR      REPL
RCHRES   4 NUTRX  DNUST  4              WDM   1665 PO4X     METR      REPL
COPY    11 OUTPUT MEAN   1                 WDM   1666 NH4P     METR      REPL
COPY    11 OUTPUT MEAN   2                 WDM   1667 PO4P     METR      REPL
RCHRES   4 PLANK  PHYCLA 1                 WDM   1668 PHCA     METR      REPL
RCHRES   4 PLANK  PKST3  4                 WDM   1669 TORN     METR      REPL
RCHRES   5 OXRX   DOX                      WDM   1681 DOXX     METR      REPL
RCHRES   5 OXRX   BOD                      WDM   1682 BODX     METR      REPL
RCHRES   5 NUTRX  DNUST  1                 WDM   1683 NO3X     METR      REPL
RCHRES   5 NUTRX  DNUST  2                 WDM   1684 NH4X     METR      REPL
RCHRES   5 NUTRX  DNUST  4                 WDM   1685 PO4X     METR      REPL
COPY    12 OUTPUT MEAN   1                 WDM   1686 NH4P     METR      REPL
COPY    12 OUTPUT MEAN   2                 WDM   1687 PO4P     METR      REPL
RCHRES   5 PLANK  PHYCLA 1                 WDM   1688 PHCA     METR      REPL
RCHRES   5 PLANK  PKST3  4                 WDM   1689 TORN     METR      REPL
RCHRES   6 OXRX   DOX                      WDM   1701 DOXX     METR      REPL
RCHRES   6 OXRX   BOD                      WDM   1702 BODX     METR      REPL
RCHRES   6 NUTRX  DNUST  1                 WDM   1703 NO3X     METR      REPL
RCHRES   6 NUTRX  DNUST  2                 WDM   1704 NH4X     METR      REPL
RCHRES   6 NUTRX  DNUST  4                 WDM   1705 PO4X     METR      REPL
COPY    14 OUTPUT MEAN   1                 WDM   1706 NH4P     METR      REPL
COPY    14 OUTPUT MEAN   2                 WDM   1707 PO4P     METR      REPL
RCHRES   6 PLANK  PHYCLA 1                 WDM   1708 PHCA     METR      REPL
RCHRES   6 PLANK  PKST3  4                 WDM   1709 TORN     METR      REPL
RCHRES   8 OXRX   DOX                      WDM   1741 DOXX     METR      REPL
RCHRES   8 OXRX   BOD                      WDM   1742 BODX     METR      REPL
RCHRES   8 NUTRX  DNUST  1                 WDM   1743 NO3X     METR      REPL
RCHRES   8 NUTRX  DNUST  2                 WDM   1744 NH4X     METR      REPL
RCHRES   8 NUTRX  DNUST  4                 WDM   1745 PO4X     METR      REPL
COPY    14 OUTPUT MEAN   1                 WDM   1746 NH4P     METR      REPL
COPY    14 OUTPUT MEAN   2                 WDM   1747 PO4P     METR      REPL
RCHRES   8 PLANK  PHYCLA 1                 WDM   1748 PHCA     METR      REPL
RCHRES   8 PLANK  PKST3  4                 WDM   1749 TORN     METR      REPL


*** sediment calibration data sets
RCHRES   1 HYDR   TAU                      WDM   9001 TAU      ENGL      REPL
RCHRES   2 HYDR   TAU                      WDM   9002 TAU      ENGL      REPL
RCHRES   3 HYDR   TAU                      WDM   9003 TAU      ENGL      REPL
RCHRES   4 HYDR   TAU                      WDM   9004 TAU      ENGL      REPL
RCHRES   5 HYDR   TAU                      WDM   9005 TAU      ENGL      REPL
RCHRES   6 HYDR   TAU                      WDM   9006 TAU      ENGL      REPL
RCHRES   7 HYDR   TAU                      WDM   9007 TAU      ENGL      REPL
RCHRES   8 HYDR   TAU                      WDM   9008 TAU      ENGL      REPL
RCHRES   9 HYDR   TAU                      WDM   9009 TAU      ENGL      REPL
PERLND 702 SEDMNT DETS                     WDM   9023 DETS     ENGL      REPL
PERLND 703 SEDMNT DETS                     WDM   9026 DETS     ENGL      REPL
PERLND 704 SEDMNT DETS                     WDM   9027 DETS     ENGL      REPL
PERLND 705 SEDMNT DETS                     WDM   9028 DETS     ENGL      REPL
PERLND 706 SEDMNT DETS                     WDM   9029 DETS     ENGL      REPL
PERLND 707 SEDMNT DETS                     WDM   9030 DETS     ENGL      REPL
PERLND 708 SEDMNT DETS                     WDM   9031 DETS     ENGL      REPL
PERLND 709 SEDMNT DETS                     WDM   9032 DETS     ENGL      REPL
PERLND 710 SEDMNT DETS                     WDM   9033 DETS     ENGL      REPL
PERLND 711 SEDMNT DETS                     WDM   9034 DETS     ENGL      REPL
PERLND 402 SEDMNT DETS                     WDM   9035 DETS     ENGL      REPL
PERLND 403 SEDMNT DETS                     WDM   9036 DETS     ENGL      REPL
PERLND 404 SEDMNT DETS                     WDM   9037 DETS     ENGL      REPL
PERLND 405 SEDMNT DETS                     WDM   9038 DETS     ENGL      REPL
PERLND 406 SEDMNT DETS                     WDM   9039 DETS     ENGL      REPL
PERLND 407 SEDMNT DETS                     WDM   9040 DETS     ENGL      REPL
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PERLND 408 SEDMNT DETS                     WDM   9041 DETS     ENGL      REPL
PERLND 409 SEDMNT DETS                     WDM   9042 DETS     ENGL      REPL
PERLND 410 SEDMNT DETS                     WDM   9043 DETS     ENGL      REPL
PERLND 411 SEDMNT DETS                     WDM   9044 DETS     ENGL      REPL
PERLND 602 SEDMNT DETS                     WDM   9045 DETS     ENGL      REPL
PERLND 603 SEDMNT DETS                     WDM   9046 DETS     ENGL      REPL
PERLND 604 SEDMNT DETS                     WDM   9047 DETS     ENGL      REPL
PERLND 605 SEDMNT DETS                     WDM   9048 DETS     ENGL      REPL
PERLND 606 SEDMNT DETS                     WDM   9049 DETS     ENGL      REPL
PERLND 607 SEDMNT DETS                     WDM   9050 DETS     ENGL      REPL
PERLND 608 SEDMNT DETS                     WDM   9051 DETS     ENGL      REPL
PERLND 609 SEDMNT DETS                     WDM   9052 DETS     ENGL      REPL
PERLND 610 SEDMNT DETS                     WDM   9053 DETS     ENGL      REPL
PERLND 611 SEDMNT DETS                     WDM   9054 DETS     ENGL      REPL

END EXT TARGETS

SCHEMATIC
<-Source->                   <--Area-->    <-Target->   <ML>  ***
<Name>   #                   <-factor->    <Name>   #      #  ***
*** Note: All PLS-RCH and ILS-RCH multiplication factors are acres.
***       Conversion factors, where applicable, are in Mass-Link.
***
*** Segment & (Upper Red Clay)
*** Tributary to Reach 1 (Upper West Br.)
PERLND 702                    669.7700     RCHRES   1      1
PERLND 703                     103.100     RCHRES   1      1
PERLND 704                     138.210     RCHRES   1      1
PERLND 705                     377.356     RCHRES   1      1
*** original mushroom area estimate
PERLND 706                    3018.848     RCHRES   1      1
PERLND 707                     377.356     RCHRES   1      1
***
PERLND 708                    1187.260     RCHRES   1      1
PERLND 709                     180.470     RCHRES   1      1
PERLND 710                      28.470     RCHRES   1      1
PERLND 711                     107.490     RCHRES   1      1
IMPLND 701                     118.260     RCHRES   1      2
IMPLND 702                     141.840     RCHRES   1      2

*** Tributary to Reach 2 (Lower W.Br. to Kennett gage)
PERLND 702                     556.810     RCHRES   2      1
PERLND 703                      23.820     RCHRES   2      1
PERLND 704                      31.450     RCHRES   2      1
PERLND 705                       0.000     RCHRES   2      1
***original mushroom estimate
PERLND 706                    1934.016     RCHRES   2      1
PERLND 707                     828.864     RCHRES   2      1
***
PERLND 708                    1192.800     RCHRES   2      1
PERLND 709                      12.640     RCHRES   2      1
PERLND 710                      10.450     RCHRES   2      1
PERLND 711                      30.920     RCHRES   2      1
IMPLND 701                      72.080     RCHRES   2      2
IMPLND 702                      33.150     RCHRES   2      2

*** Tributary to Reach 3 (East Br. to conf W.Br)
PERLND 702                     943.250     RCHRES   3      1
PERLND 703                     122.940     RCHRES   3      1
PERLND 704                      64.000     RCHRES   3      1
PERLND 705                       0.000     RCHRES   3      1
***original mushroom estimate
PERLND 706                    2098.173     RCHRES   3      1
PERLND 707                     899.217     RCHRES   3      1
***
PERLND 708                    1425.110     RCHRES   3      1
PERLND 709                     368.250     RCHRES   3      1
PERLND 710                      38.470     RCHRES   3      1
PERLND 711                     148.400     RCHRES   3      1
IMPLND 701                     157.490     RCHRES   3      2
IMPLND 702                      68.690     RCHRES   3      2

    Reach Connections ***
RCHRES   1                                 RCHRES   2      3
RCHRES   3                                 RCHRES   2      4
RCHRES   2                                 RCHRES   4      4

*** Segment 4 (East Br. and mainstem Red Clay)

*** Tributary to Reach 4 (Kennett gage to Ashland)
PERLND 402                    1161.330     RCHRES   4      1
PERLND 403                      75.870     RCHRES   4      1
PERLND 404                      32.700     RCHRES   4      1
PERLND 405                      57.504     RCHRES   4      1
PERLND 406                     460.032     RCHRES   4      1
PERLND 407                      57.504     RCHRES   4      1
PERLND 408                     930.100     RCHRES   4      1
PERLND 409                     257.520     RCHRES   4      1
PERLND 410                      26.440     RCHRES   4      1
PERLND 411                      18.770     RCHRES   4      1
IMPLND 401                     161.550     RCHRES   4      2
IMPLND 402                      32.910     RCHRES   4      2
```

```
*** Tributary to Reach 5 (Ashland to Wooddale gage)
PERLND 402                    1079.360     RCHRES   5      1
PERLND 403                      74.560     RCHRES   5      1
PERLND 404                       9.330     RCHRES   5      1
PERLND 405                       0.000     RCHRES   5      1
PERLND 406                     492.060     RCHRES   5      1
PERLND 407                       0.000     RCHRES   5      1
PERLND 408                    1266.250     RCHRES   5      1
PERLND 409                     199.560     RCHRES   5      1
PERLND 410                      40.640     RCHRES   5      1
PERLND 411                      29.100     RCHRES   5      1
IMPLND 401                     151.890     RCHRES   5      2
IMPLND 402                      10.320     RCHRES   5      2
*** Tributary to Reach 6 (Burroughs Run)
PERLND 402                    1085.790     RCHRES   6      1
PERLND 403                       0.000     RCHRES   6      1
PERLND 404                       8.550     RCHRES   6      1
PERLND 405                       0.000     RCHRES   6      1
*** original ag land
PERLND 406                    1928.530     RCHRES   6      1
***
PERLND 407                       0.000     RCHRES   6      1
PERLND 408                    1140.260     RCHRES   6      1
***original open
PERLND 409                     232.900     RCHRES   6      1
***
PERLND 410                       6.010     RCHRES   6      1
PERLND 411                      12.480     RCHRES   6      1
IMPLND 401                     120.640     RCHRES   6      2
IMPLND 402                       8.550     RCHRES   6      2
*** Tributary to Reach 7 (Hoopes Reservoir)
PERLND 402   ***               350.380     RCHRES   7      1
PERLND 403   ***                 0.440     RCHRES   7      1
PERLND 404   ***                 6.420     RCHRES   7      1
PERLND 405   ***                     0     RCHRES   7      1
PERLND 406   ***                97.200     RCHRES   7      1
PERLND 407   ***                     0     RCHRES   7      1
PERLND 408   ***               596.300     RCHRES   7      1
PERLND 409   ***                39.980     RCHRES   7      1
PERLND 410   ***               192.370     RCHRES   7      1
PERLND 411   ***                14.930     RCHRES   7      1
IMPLND 401   ***                39.120     RCHRES   7      2
IMPLND 402   ***                 6.450     RCHRES   7      2

    Reach Connections ***
RCHRES   4                                 RCHRES   5      4
RCHRES   6                                 RCHRES   5      3
RCHRES   7    ***                          RCHRES   5      3
RCHRES   5                                 RCHRES   8      3

***
*** Segment 6 (Wooddale gage to confl.)

*** Tributary to Reach 8 (Wooddale to Stanton gage)
PERLND 602                      52.700     RCHRES   8      1
PERLND 603                    1215.470     RCHRES   8      1
PERLND 604                     182.160     RCHRES   8      1
PERLND 605                       0.000     RCHRES   8      1
PERLND 606                      54.610     RCHRES   8      1
PERLND 607                       0.000     RCHRES   8      1
PERLND 608                     464.550     RCHRES   8      1
PERLND 609                     475.640     RCHRES   8      1
PERLND 610                      47.930     RCHRES   8      1
PERLND 611                     216.950     RCHRES   8      1
IMPLND 601                     526.770     RCHRES   8      2
IMPLND 602                     206.210     RCHRES   8      2
*** Tributary to Reach 9 (Stanton gage to confl.)
PERLND 602                       0.040     RCHRES   9      1
PERLND 603                     501.850     RCHRES   9      1
PERLND 604                      52.640     RCHRES   9      1
PERLND 605                           0     RCHRES   9      1
PERLND 606                           0     RCHRES   9      1
PERLND 607                           0     RCHRES   9      1
PERLND 608                     112.890     RCHRES   9      1
PERLND 609                      41.680     RCHRES   9      1
PERLND 610                       4.860     RCHRES   9      1
PERLND 611                     109.470     RCHRES   9      1
IMPLND 601                     215.080     RCHRES   9      2
IMPLND 602                      64.800     RCHRES   9      2

    Reach Connections ***
RCHRES   8                                 RCHRES   9      4

*** HSPEXP ***
    Kennett Sq. gage - Output from Reach 2  ***
PERLND 702                    2169.830     COPY   200     91
PERLND 703                     249.890     COPY   200     91
PERLND 704                     233.660     COPY   200     91
PERLND 705                     377.356     COPY   200     91
PERLND 706                    7051.037     COPY   200     91
PERLND 707                    2105.437     COPY   200     91
PERLND 708                    3805.170     COPY   200     91
```

```
PERLND 709                     561.360     COPY   200     91
PERLND 710                      77.390     COPY   200     91
PERLND 711                     286.810     COPY   200     91
IMPLND 701                     347.830     COPY   200     92
IMPLND 702                     243.680     COPY   200     92
     Red Clay at Wooddale gage - Output from reach 5 ***
PERLND 702                    2169.830     COPY   300     91
PERLND 703                     249.890     COPY   300     91
PERLND 704                     233.660     COPY   300     91
PERLND 705                     377.356     COPY   300     91
PERLND 706                    7051.037     COPY   300     91
PERLND 707                    2105.437     COPY   300     91
PERLND 708                    3805.170     COPY   300     91
PERLND 709                     561.360     COPY   300     91
PERLND 710                      77.390     COPY   300     91
PERLND 711                     286.810     COPY   300     91
IMPLND 701                     347.830     COPY   300     92
IMPLND 702                     243.680     COPY   300     92
PERLND 402                    3326.480     COPY   300     91
PERLND 403                     150.430     COPY   300     91
PERLND 404                      50.580     COPY   300     91
PERLND 405                      57.504     COPY   300     91
PERLND 406                    2880.682     COPY   300     91
PERLND 407                      57.504     COPY   300     91
PERLND 408                    3336.610     COPY   300     91
PERLND 409                     689.980     COPY   300     91
PERLND 410                      73.090     COPY   300     91
PERLND 411                      60.350     COPY   300     91
IMPLND 401                     434.080     COPY   300     92
IMPLND 402                      51.780     COPY   300     92
     Red Clay at Stanton gage output from reach 8 ***
PERLND 702                    2169.830     COPY   400     91
PERLND 703                     249.890     COPY   400     91
PERLND 704                     233.660     COPY   400     91
PERLND 705                     377.356     COPY   400     91
PERLND 706                    7051.037     COPY   400     91
PERLND 707                    2105.437     COPY   400     91
PERLND 708                    3805.170     COPY   400     91
PERLND 709                     561.360     COPY   400     91
PERLND 710                      77.390     COPY   400     91
PERLND 711                     286.810     COPY   400     91
IMPLND 701                     347.830     COPY   400     92
IMPLND 702                     243.680     COPY   400     92
PERLND 402                    3326.480     COPY   400     91
PERLND 403                     150.430     COPY   400     91
PERLND 404                      50.580     COPY   400     91
PERLND 405                      57.504     COPY   400     91
PERLND 406                    2880.682     COPY   400     91
PERLND 407                      57.504     COPY   400     91
PERLND 408                    3336.610     COPY   400     91
PERLND 409                     689.980     COPY   400     91
PERLND 410                      73.090     COPY   400     91
PERLND 411                      60.350     COPY   400     91
IMPLND 401                     434.080     COPY   400     92
IMPLND 402                      51.780     COPY   400     92
PERLND 602                       52.70     COPY   400     91
PERLND 603                     1215.47     COPY   400     91
PERLND 604                      182.16     COPY   400     91
PERLND 605                           0     COPY   400     91
PERLND 606                      54.610     COPY   400     91
PERLND 607                           0     COPY   400     91
PERLND 608                      464.55     COPY   400     91
PERLND 609                      475.64     COPY   400     91
PERLND 610                       47.93     COPY   400     91
PERLND 611                      216.95     COPY   400     91
IMPLND 601                      526.77     COPY   400     92
IMPLND 602                      206.21     COPY   400     92
END SCHEMATIC

MASS-LINK
  MASS-LINK        1
<Srce>     <-Grp> <-Member-><--Mult-->     <Targ>         <-Grp> <-Member-> ***
<Name>     <Name> <Name> # #<-factor->     <Name>         <Name> <Name> # # ***
PERLND     PWATER PERO       0.0833333     RCHRES         INFLOW IVOL
PERLND     SEDMNT SOSED           0.10     RCHRES         INFLOW ISED   1
PERLND     SEDMNT SOSED           0.40     RCHRES         INFLOW ISED   2
PERLND     SEDMNT SOSED           0.50     RCHRES         INFLOW ISED   3
PERLND     PWTGAS POHT                     RCHRES         INFLOW IHEAT
PERLND     PWTGAS PODOXM                   RCHRES         INFLOW OXIF   1
PERLND     PQUAL  POQUAL 1                 RCHRES         INFLOW NUIF1  1
PERLND     PQUAL  POQUAL 2                 RCHRES         INFLOW NUIF1  2
PERLND     PQUAL  POQUAL 3                 RCHRES         INFLOW NUIF1  4
PERLND     PQUAL  POQUAL 4                 RCHRES         INFLOW OXIF   2
PERLND     PQUAL  POQUAL 5                 RCHRES         INFLOW PKIF   3
  END MASS-LINK    1

  MASS-LINK        2
<Srce>     <-Grp> <-Member-><--Mult-->     <Targ>         <-Grp> <-Member-> ***
<Name>     <Name> <Name> # #<-factor->     <Name>         <Name> <Name> # # ***
IMPLND     IWATER SURO       0.0833333     RCHRES         INFLOW IVOL
IMPLND     SOLIDS SOSLD           0.10     RCHRES         INFLOW ISED   1
IMPLND     SOLIDS SOSLD           0.40     RCHRES         INFLOW ISED   2
```

```
IMPLND     SOLIDS SOSLD           0.50     RCHRES         INFLOW ISED   3
IMPLND     IWTGAS SOHT                     RCHRES         INFLOW IHEAT
IMPLND     IWTGAS SODOXM                   RCHRES         INFLOW OXIF   1
IMPLND     IQUAL  SOQUAL 1                 RCHRES         INFLOW NUIF1  1
IMPLND     IQUAL  SOQUAL 2                 RCHRES         INFLOW NUIF1  2
IMPLND     IQUAL  SOQUAL 3                 RCHRES         INFLOW NUIF1  4
IMPLND     IQUAL  SOQUAL 4                 RCHRES         INFLOW OXIF   2
  END MASS-LINK    2

  MASS-LINK        3
<Srce>     <-Grp> <-Member-><--Mult-->     <Targ>         <-Grp> <-Member-> ***
<Name>     <Name> <Name> # #<-factor->     <Name>         <Name> <Name> # # ***
RCHRES     ROFLOW                          RCHRES         INFLOW
  END MASS-LINK    3

  MASS-LINK        4
<Srce>     <-Grp> <-Member-><--Mult-->     <Targ>         <-Grp> <-Member-> ***
<Name>     <Name> <Name> # #<-factor->     <Name>         <Name> <Name> # # ***
RCHRES     OFLOW         1                 RCHRES         INFLOW
  END MASS-LINK    4

  MASS-LINK       91
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->strg <Name>                <Name> x x  ***
PERLND     PWATER SURO                     COPY           INPUT  MEAN   1
PERLND     PWATER IFWO                     COPY           INPUT  MEAN   2
PERLND     PWATER AGWO                     COPY           INPUT  MEAN   3
PERLND     PWATER PET                      COPY           INPUT  MEAN   5
PERLND     PWATER TAET                     COPY           INPUT  MEAN   6
PERLND     PWATER UZS                      COPY           INPUT  MEAN   7
PERLND     PWATER LZS                      COPY           INPUT  MEAN   8
PERLND     PWATER AGWS                     COPY           INPUT  MEAN   9
PERLND     SEDMNT SOSED                    COPY           INPUT  MEAN  10
PERLND     PQUAL  POQUAL 1                 COPY           INPUT  MEAN  11
PERLND     PQUAL  POQUAL 2                 COPY           INPUT  MEAN  12
PERLND     PQUAL  POQUAL 3                 COPY           INPUT  MEAN  13
  END MASS-LINK   91

  MASS-LINK       92
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->strg <Name>                <Name> x x  ***
IMPLND     IWATER SURO                     COPY           INPUT  MEAN   1
IMPLND     IWATER PET                      COPY           INPUT  MEAN   5
IMPLND     IWATER IMPEV                    COPY           INPUT  MEAN   6
IMPLND     SOLIDS SOSLD                    COPY           INPUT  MEAN  14
IMPLND     IQUAL  SOQUAL 1                 COPY           INPUT  MEAN  15
IMPLND     IQUAL  SOQUAL 2                 COPY           INPUT  MEAN  16
IMPLND     IQUAL  SOQUAL 3                 COPY           INPUT  MEAN  17
  END MASS-LINK   92

  MASS-LINK       93
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->strg <Name>                <Name> x x  ***
COPY       OUTPUT MEAN   1                 COPY           INPUT  MEAN   1
COPY       OUTPUT MEAN   2                 COPY           INPUT  MEAN   2
COPY       OUTPUT MEAN   3                 COPY           INPUT  MEAN   3
COPY       OUTPUT MEAN   4                 COPY           INPUT  MEAN   4
COPY       OUTPUT MEAN   5                 COPY           INPUT  MEAN   5
COPY       OUTPUT MEAN   6                 COPY           INPUT  MEAN   6
COPY       OUTPUT MEAN   7                 COPY           INPUT  MEAN   7
COPY       OUTPUT MEAN   8                 COPY           INPUT  MEAN   8
COPY       OUTPUT MEAN   9                 COPY           INPUT  MEAN   9
COPY       OUTPUT MEAN  10                 COPY           INPUT  MEAN  10
COPY       OUTPUT MEAN  11                 COPY           INPUT  MEAN  11
COPY       OUTPUT MEAN  12                 COPY           INPUT  MEAN  12
COPY       OUTPUT MEAN  13                 COPY           INPUT  MEAN  13
COPY       OUTPUT MEAN  14                 COPY           INPUT  MEAN  14
COPY       OUTPUT MEAN  15                 COPY           INPUT  MEAN  15
COPY       OUTPUT MEAN  16                 COPY           INPUT  MEAN  16
COPY       OUTPUT MEAN  17                 COPY           INPUT  MEAN  17
  END MASS-LINK   93

END MASS-LINK

NETWORK
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member->  ***
<Name>   #        <Name> # #<-factor->strg <Name>   #   #        <Name> # #  ***
*** Results for calibration
     PARTICULATE N (ADSORBED NH3 + ORG N) ***
RCHRES   2 NUTRX  RSNH4  4                 GENER    1     INPUT  ONE
RCHRES   2 HYDR   VOL                      GENER    1     INPUT  TWO
GENER    1 OUTPUT TIMSER       0.368       COPY    10     INPUT  MEAN   1
RCHRES   4 NUTRX  RSNH4  4                 GENER    3     INPUT  ONE
RCHRES   4 HYDR   VOL                      GENER    3     INPUT  TWO
GENER    3 OUTPUT TIMSER       0.368       COPY    11     INPUT  MEAN   1
RCHRES   5 NUTRX  RSNH4  4                 GENER    5     INPUT  ONE
RCHRES   5 HYDR   VOL                      GENER    5     INPUT  TWO
GENER    5 OUTPUT TIMSER       0.368       COPY    12     INPUT  MEAN   1
RCHRES   6 NUTRX  RSNH4  4                 GENER    7     INPUT  ONE
RCHRES   6 HYDR   VOL                      GENER    7     INPUT  TWO
GENER    7 OUTPUT TIMSER       0.368       COPY    13     INPUT  MEAN   1
RCHRES   8 NUTRX  RSNH4  4                 GENER    9     INPUT  ONE
```

```
RCHRES   8 HYDR   VOL                      GENER    9     INPUT  TWO
GENER    9 OUTPUT TIMSER       0.368       COPY    14     INPUT  MEAN   1
     PARTICULATE P (ADSORBED PO4 + ORG P) ***
RCHRES   2 NUTRX  RSPO4  4                 GENER    2     INPUT  ONE
RCHRES   2 HYDR   VOL                      GENER    2     INPUT  TWO
GENER    2 OUTPUT TIMSER       0.368       COPY    10     INPUT  MEAN   2
RCHRES   4 NUTRX  RSPO4  4                 GENER    4     INPUT  ONE
RCHRES   4 HYDR   VOL                      GENER    4     INPUT  TWO
GENER    4 OUTPUT TIMSER       0.368       COPY    11     INPUT  MEAN   2
RCHRES   5 NUTRX  RSPO4  4                 GENER    6     INPUT  ONE
RCHRES   5 HYDR   VOL                      GENER    6     INPUT  TWO
GENER    6 OUTPUT TIMSER       0.368       COPY    12     INPUT  MEAN   2
RCHRES   6 NUTRX  RSPO4  4                 GENER    8     INPUT  ONE
RCHRES   6 HYDR   VOL                      GENER    8     INPUT  TWO
GENER    8 OUTPUT TIMSER       0.368       COPY    13     INPUT  MEAN   2
RCHRES   8 NUTRX  RSPO4  4                 GENER   10     INPUT  ONE
RCHRES   8 HYDR   VOL                      GENER   10     INPUT  TWO
GENER   10 OUTPUT TIMSER       0.368       COPY    14     INPUT  MEAN   2
END NETWORK

GENER
  OPCODE
    #thru# code ***
    1   14   19
  END OPCODE
END GENER


END RUN
```